This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

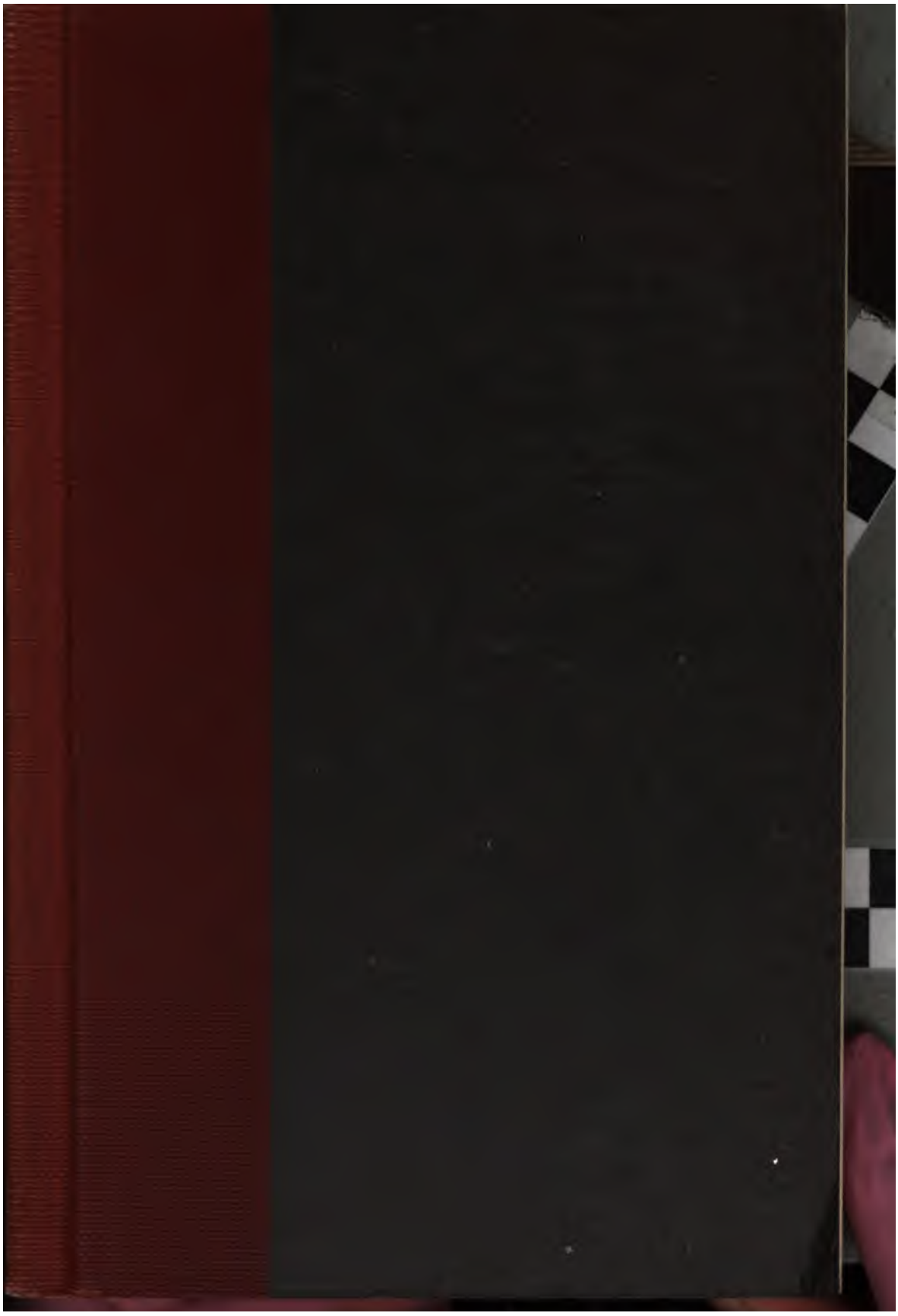
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



BRANNER
GEOLOGICAL LIBRARY

STANFORD UNIVERSITY
LIBRARIES

Water-Supply and Irrigation Paper No. 76

Series { L, Quality of Water, 4
M, Methods of Hydrographic Investigation, 3

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

OBSERVATIONS ON THE FLOW OF RIVERS

IN THE

VICINITY OF NEW YORK CITY

BY

HENRY ALBERT PRESSEY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

BRANNER
GEOLOGICAL LIBRARY

STANFORD UNIVERSITY LIBRARIES

Water-Supply and Irrigation Paper No. 76

Series { L. Quality of Water, 4
M. Methods of Hydrographic Investigation, 3

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

OBSERVATIONS ON THE FLOW OF RIVERS

IN THE

VICINITY OF NEW YORK CITY

BY

HENRY ALBERT PRESSEY

HINGTON
PRINTING OFFICE
1903

664285

CONTENTS.

	Page.
er of transmittal	7
oduction	9
hods of measuring velocity in river channels	14
Floats	15
General methods	15
Surface floats	15
Subsurface or double floats	16
Rod or tube floats	17
Weirs	18
Current meters	19
tical velocity curves on streams without ice cover	20
River stations at which curves were obtained	72
Catskill Creek at South Cairo, N. Y	27
Esopus Creek at Kingston, N. Y	28
Wallkill River at New Paltz, N. Y	28
Rondout Creek at Rosendale, N. Y	28
Fishkill Creek at Glenham, N. Y	28
Tenmile River below Dover Plains, N. Y	29
Housatonic River at Gaylordsville, Conn	29
Discussion of tables	29
w of rivers under ice, smooth and unbroken cover	48
w of rivers under ice, broken and tilted cover	64
lity of river water	67
Turbidity and color	67
Turbidity	68
Proposed turbidity standard	69
Method of application of platinum-wire process	69
Method of making observations	71
Color	73
Color standards	74
Filling the tubes	75
Holding the tubes	75
Background	75
Turbid water	75
Highly colored waters	75
Cleaning the tubes	76
Alkalinity	76
Permanent hardness	76
e heights and discharge measurements	86
x	105

ILLUSTRATIONS.

		Page
PLATE	I. *A*, Current meter in use suspended from a bridge; *B*, Cable and car used to measure discharge of river	18
	II. Price electric current meters	20
	III. Gaging station on Catskill Creek at South Cairo, N. Y	26
	IV. Gaging station on Esopus Creek at Kingston, N. Y	26
	V. Gaging station on Wallkill River at New Paltz, N. Y	26
	VI. Gaging station on Rondout Creek at Rosendale, N. Y	28
	VII. Gaging station on Housatonic River at Gaylordsville, Conn	28
	VIII. *A*, Cross section, Wallkill River at New Paltz, showing curves of equal velocity, as determined by current-meter measurements; *B*, Horizontal velocity curves on Wallkill River at New Paltz, constructed from data obtained on the same date as that plotted in *A*	30
	IX. Diagram showing results of turbidity observations	70
	X. Tubes and disks for measuring in the field the color of river water	72
	XI. Diagram showing results of color observations	74
	XII. Diagram showing results of alkalinity observations	76
	XIII. Diagram showing results of hardness observations	78
FIG.	1. Cross-section curve on Esopus Creek at Kingston, showing curves of equal velocity as determined by current-meter measurements, there being no ice cover	22
	2. Mean vertical velocity curves for Esopus, Rondout, Catskill, and Fishkill creeks, and Wallkill, Tenmile, and Housatonic rivers	24
	3. Comparison of the general mean velocity curve with the mean curve for smooth bed and the mean curve for rough bed	25
	4. Cross section of Wallkill River at New Paltz showing ice cover and curves of equal velocity in river channel	48
	5. Mean vertical velocity curves on Wallkill River, with ice cover, showing the effect upon the curve of variation in depth of water	60
	6. Mean vertical velocity curves on Esopus and Rondout creeks and Wallkill River, under ice cover, showing the comparatively slight variation in vertical velocity curves of rivers of this character	61
	7. Comparison of curves for various depths of water under ice cover with the mean of all curves taken under ice	62
	8. New folding turbidity stick	86

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 23, 1902.

SIR: I transmit herewith manuscript for Water-Supply and Irrigation Paper No. 76, by H. A. Pressey, entitled Observations on the Flow of Rivers in the Vicinity of New York City.

Respectfully,

F. H. NEWELL,
Hydrographer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

OBSERVATIONS ON THE FLOW OF RIVERS IN THE VICINITY OF NEW YORK CITY.

By H. A. PRESSEY.

INTRODUCTION.

One of the chief resources of the United States is its water supply. The prominent industrial position of several States is due largely to the abundance of their available water. It has recently been stated that "the preeminent position of the State of New York is due almost entirely to her great natural resources;" that "her inland rivers, with their great water powers, have been in the past and will continue to be in the future a perpetual source of wealth," and that "the history of the State's progress during the nineteenth century is largely a history of the development of her water resources." These remarks apply quite as aptly to some of the New England States, as they could not have held the front rank in the industrial world for so many years were it not for the very extensive utilization of the magnificent waterfalls of that region. In the Southern Atlantic States the great developments during the last few years are due largely to the development and utilization of water powers.

There is not a State along the Atlantic coast, except Delaware, that does not contain water powers, developed and undeveloped, and, contrary to the opinion of many, there never was a decade in the history of our country when the development of water power made such strides as during the last ten years. According to the returns of the Twelfth United States Census the increase in the utilization of water power in the United States in the ten years from 1890 to 1900 was about 30 per cent, or 472,361 horsepower. In some States this increase was remarkable, as, for instance, in Maine, where in the last decade the developed power increased 60 per cent.

The importance of our water powers as a source of wealth can hardly be overestimated. This power is not confined, however, to the Eastern States, for in the great Central Northwest, on the Pacific slope, and elsewhere there are water powers of great size and value, many of which form the basis of the industrial life of large communities. In the broad, flat plains of the United States west of the Mississippi

the rivers are valuable from another standpoint. In this region the streams commonly lack the fall required for power development, but here the water supply is, perhaps, more vital to the life of the region than in the coastal States. Great areas of land depend for water largely upon the rivers in their vicinity and upon artificial means for raising and distributing it over their soils. Without water there can be no life in this region; with water, vast areas can be reclaimed as agricultural land of great fertility.

In most parts of the country the public water supply of the cities and towns must be derived from the rivers. Large sums are expended every year in conducting water from the streams to the centers of population. Before this money is expended it is of the greatest importance to know that there is sufficient water at all times for the use of the town. Too often have great hydraulic works been built before proper investigation has been made of the flow of a stream, and great financial loss has resulted.

It is to furnish information upon which to base estimates of available water supply that the Hydrographic Division of the United States Geological Survey has been, during the last fourteen years, collecting data in regard to the flow of rivers in the United States, and their variation from season to season and throughout a series of years. The necessity for such data is frequently brought to the attention of the engineer, sometimes in a most startling manner. The lack of this information frequently leads to the most disastrous mistakes in the construction of hydraulic works. One of the best examples of this in the design of a hydraulic plant was the construction of a dam and water-power plant at Austin, Tex. After an expenditure of $1,600,000 it was found that a grave mistake had been made in the estimate of the low-water flow. The works were constructed by the city in accordance with a vote of the citizens of Austin in 1890. It was estimated that 14,000 horsepower could be developed, and the people felt that their city was to become a great manufacturing center. No hydrographic data had been collected, except from the hazy memory of the "oldest inhabitant." In the spring of 1890 a measurement of flow giving 1,000 cubic feet per second was taken as the minimum. This estimate was more than five times too great, as was shown by subsequent measurements. An error of 500 per cent had been made in the estimate, but this was not ascertained until the works were nearly completed.

Mistakes of this kind have occurred in every part of the country in hydraulic works. The Sweetwater dam in California in a good example of a project carried through on insufficient data. The dam was built after a series of wet years and was soon after filled to overflowing, so that increased spillways were constructed, but since that time the water in the reservoir has never reached an elevation near the crest of the spillways, and during most of the time there has been the greatest scarcity of water.

The Bear Valley dam is a more marked case, as the reservoir formed by the dam has been practically dry for several years, so that wells have been driven in the bottom of it.

The Gila Bend, Arizona, project is another example of the expenditure of a large sum—$900,000—upon insufficient data, and subsequent abandonment of the scheme. In this project the dam was carried away before its completion, but had it been completed the scheme must have proved a financial failure.

Many diversion canal projects for irrigation have been either partial or complete failures on account of shortage of water; that is, developments have been made far beyond the capacity of the stream.

A great number of water-power plants have been constructed upon insufficient data, and later, auxiliary steam has been found necessary. Allowance was not made in the original estimates, so that in a number of instances the project has been found unprofitable. Knowl- of the flood flow is also of great importance in designing the dams and waste ways.

Frequently the cause of such errors is a complete ignorance of the hydrographic conditions in the drainage basin of the stream and often of the region in which the stream is located. In a few cases no adequate efforts have been made to obtain information; perhaps a single measurement may have been made at a time when a local resident informed the investigator that the "river is now as low as it ever gets." In order to test the accuracy of such methods, the writer has often asked old inhabitants on the banks of the river as to the variation in the river height, and has been informed that "it is now at its lowest stage;" or, that "it never falls more than 2 or 3 inches below its present height." At a later visit to the stream in the same season the river surface has been found to be at an elevation 2 or 3 feet below its previous stage. The word of the oldest inhabitant is sometimes fairly reliable as to high water, but his information as to low-water stages should be carefully checked, and the fact that a number of the inhabitants say that the river never goes lower is not sufficient evidence upon which to construct hydraulic works.

Rainfall data are often used in discussing the variation of flow of a stream, and numerous theories and formulas are applied to show that the flow can never fall below a certain amount, these theories to be sadly shaken later, when measurements are made and the facts ascertained. In a few cases greater weight has been given to these theories than to actual measurements, even though the measurements were made by a careful and reliable engineer. The measurements were lower, perhaps, than theory would suggest, and therefore the measurements must be wrong.

In studying the flow of a stream every possible source of information should be utilized—even the ideas of the oldest inhabitants—but to most engineers it is very reassuring to know that actual measure-

ments of the discharge have been made and are available for use. If measurements of the stream under consideration have not been made, then results obtained from measurements of rivers in the immediate vicinity can be used to advantage, care being taken that the hydrographic, topographic, geologic, and forest conditions in the two basins are similar.

As an example of the difficulties under which a prospective investor labors, there are now before the writer reports upon a certain stream in New York State made by five different engineers, all of good standing, in which estimates of the minimum flow of the stream under consideration vary from 0.20 to 0.40 cubic foot per second per square mile; that is, the minimum flow given by one engineer is just twice that given by another. As the development of a water power is limited largely by the low-water flow, the uncertainties arising from such divergent opinions are apparent. Since these reports were made (1900–1901) the flow of this stream has been measured, and the lowest estimate made by the engineers has been shown to be at least 100 per cent too great. In estimates of this kind facts are needed—that is, actual measurements of discharge.

No further discussion is probably necessary to convince most thinking people that the measurement of the larger streams of the United States is an important undertaking, and that capital will be invested in power developments, irrigation, sanitary and other hydraulic works more freely when information as to the flow of the streams is available.

In making measurements of streams it is of course desirable that rapid and economical methods be used, if such are of sufficient accuracy. Methods of stream measurements have been discussed in Water-Supply Paper No. 56, and it is not the purpose of this paper to deal with that question extensively, but rather to point out certain facts developed, during the last few months, by measurements of streams in the southern part of New York State, with the idea that some of the data obtained from these measurements may be useful in studying the flow of other streams and may assist in the selection of methods that will expedite the work and yet give results sufficiently accurate for all practical purposes.

In considering the future demands of the city of New York for water several additional sources of supply have been suggested: Housatonic River, Tenmile River, Wallkill River, Rondout Creek, Esopus Creek, and Catskill Creek, the Hudson River or some of its upper tributaries, Lake George, Lake Champlain, and the Great Lakes. The three last-named sources have been discussed in print somewhat extensively[a] and will not be taken up here. It has been found that the supply from Lake George would not be adequate; that Lake

[a] Report of Merchants' Association of New York on the water supply of the city of New York, August, 1900.

Champlain is at too low an elevation for economical use, and that the supply from the Great Lakes would entail great and unnecessary expense. The water from the Hudson River might be taken near its headwaters and conducted to New York City by a long aqueduct, or the intake might be located just above Poughkeepsie, in which case the water would have to be pumped from the river and filtered before delivery to the city. In either case it is important to know the discharge of the Hudson at various seasons of the year to determine the quantity available and also the effect of the diversion of water upon the regimen of the river.

The United States Geological Survey has for several years been measuring the daily flow of streams throughout the United States, the results of these measurements being used for different purposes, including irrigation, water-power, and sanitary constructions.

Measurements of flow of Schroon River at Warrensburg and of the Hudson at Fort Edward and Mechanicville have been made, also of the Mohawk and its chief tributaries at various points, and the results of these have been published in the annual reports.

The measurements of the rivers discussed in this paper were started at the suggestion of Mr. George N. Birdsall, chief engineer Bureau of Water Supply, New York City, in order that data might be available for investigations as to additional water supply for New York City. The following stations were established by the United States Geological Survey during the summer of 1901 and have been maintained continuously since that time.

Gaging stations on rivers near New York City.

Stream.	Location of gaging station.	Drainage area—		
		Above proposed reservoir.	Above gaging station.	Above mouth.
		Sq. miles.	*Sq. miles.*	*Sq. miles.*
Tenmile River	Dover Plains, N. Y	200	195	195
Housatonic River	Gaylordsville, Conn	1,020	1,020	1,580
Catskill Creek	South Cairo, N. Y	140	260	394
Esopus Creek	Kingston, N. Y	242	312	417
Wallkill River	New Paltz, N. Y	464	735	779
Rondout Creek	Rosendale, N. Y	184	365	[a]369
Fishkill Creek	Glenham, N. Y	158	198	204

[a] Above junction with Wallkill River.

A reconnaissance of each of these streams was made, and stations were selected at points where measurements could be most accurately made, and as far as practicable at points where it was thought knowledge of the flow would be *most* desired in the future study of these

watersheds as sources of increased supply for New York. The results of the observations at these stations have been published in the Water-Supply Papers of the Survey. The height of the water at each station has been noted twice each day by a local observer and current-meter measurements have been made at frequent intervals by a hydrographer. From these meter measurements a rating curve has been drawn for each station which shows the relation between the height of the water in the river and the discharge. From this curve and the daily mean gage height the flow of the river for each day in the year since the establishment of the station can be determined. These data will be of the greatest importance to the engineers selecting the source of supply, as they furnish the first continuous record of the flow of these streams and give a basis upon which to compute the supply available from each stream, which, with the topographic maps of the survey and the detailed surveys of the reservoir sites, will give complete data for the estimate of the quantity of water that can be furnished by each of these drainage basins and of the relative cost per million gallons of the supply from each.

In addition to the measurement of the discharge, determinations of turbidity, color, alkalinity, and hardness have been made upon each of these streams and are now being continued, and it is thought that these data will prove valuable in the final selection of the new source of supply. Results are given in the Water-Supply Papers of the United States Geological Survey, and are tabulated at the end of this paper.

In making gagings at these stations it was thought desirable to investigate the variations of flow in different parts of the river channel, in order to determine at what points the velocity could be measured to ascertain the mean velocity in the channel without unnecessary expense or loss of time. Before taking up the measurements and the vertical velocity curves constructed, it may not be out of place to describe briefly some of the methods used for the measurement of streams.

METHODS OF MEASURING VELOCITY IN RIVER CHANNELS.

There are in common use a number of methods of measuring the flow of rivers. In general these involve the determination of the mean velocity of the current and the area of the cross section of the stream. The latter is easily computed from soundings made at frequent intervals across the channel. These soundings must be taken at intervals so short that the bottom of the river may be considered a straight line between soundings. Usually the velocity of the current is determined in sections of the river channel, these sections extending between the points of soundings. The summation of the area of each of these sections gives the total area of the cross section. When the

total flow of the river is known and is divided by the area of the cross section the result is called the mean velocity of the river. It is this mean velocity that we try to determine in any method of stream measurement, but, as a matter of fact, it can not be actually determined until the total flow is known.

In the determination of the mean velocity of the current there are a number of methods giving results more or less accurate, all of which should be familiar to the engineer, so that the method best suited to the conditions at hand may be applied.

FLOATS.

GENERAL METHODS.

Floats are frequently employed to determine the velocity of the current. There are three general types in common use: First, surface floats; second, subsurface or double floats; third, tube or rod floats. The general method of procedure is the same whichever form of float is used. The site for making a float measurement should be on a straight reach, having a fairly uniform cross section. The flow of the water should be regular, without sudden rapids or stretches of still water, and should exhibit no tendencies to form eddies or cross currents caused by irregularities in the channel or resulting from the effect of a sharp bend above the reach. The course of the floats should have a length of from 100 to 300 feet, and the areas of cross section at the upper and lower ends of this course should be carefully determined by soundings. When courses more than 100 feet in length are selected, it is desirable that additional cross sections, at equal intervals from one another, should be measured. As a preliminary step, a base line should be laid out by tape on the bank as nearly as possible parallel with the stream, and points should be marked opposite the cross sections to be used. If the stream is not too wide the soundings in the cross sections can be taken most conveniently along a tagged rope stretched across the channel at right angles to the base. If the depth does not exceed 4 feet this can be done by wading, the depth being read on a rod graduated to feet and tenths. Should the depth of the channel or the temperature of the water make wading impossible, a boat may be used. On large rivers, where a tagged rope can not be employed, the boat from which the soundings are to be made should be located by simple triangulation. Soundings should be read to tenths of a foot and be taken preferably at equal distances apart. In deep rivers a tagged rope or chain with lead weight can be substituted for the rod.

SURFACE FLOATS.

In reconnaissance work, in which the equipment is as a rule limited by transportation facilities, surface floats consisting of chips will be found most convenient. The use of rod floats, though giving more

directly the mean velocity, has many disadvantages, and should no be attempted unless the time and opportunity permit of obtainin floats of the required lengths. In the simplest case but one man i needed to make the observations. The surface floats should b thrown into the stream a considerable distance above the first cros section. The hydrographer should attempt to start the floats, succes sively, at different distances from the shore in order to determine th velocity in different parts of the channel. The time of the passag of each float between the upper and lower cross section should b noted, preferably by a stop watch, and also the position of each flo with respect to the tags on the ropes. This will enable the hydrog rapher to determine whether or not he succeeds in covering th different parts of the stream, and it will serve as an aid in the com putation. The observations should be continued until all parts o the stream have been covered.

On wide rivers range poles may be established on opposite shore to mark the upper and lower cross sections. The location of each float as it crosses these imaginary lines can readily be recorded by triangulation. A light traverse plane table will be found especially useful in obtaining a graphic record.

The surface floats show approximately the surface velocity of th stream at the point of measurement. The results obtained by thi method are subject to errors due to wind and surface currents an eddies. The velocity shown is that of the surface of the river, whil that required for computation of discharge is the mean velocity of th cross section. Unfortunately, the relation of the surface to the mea velocity of the vertical is not constant, yet for streams of the sam general character of bed, banks, velocity, etc., the ratio is sufficientl constant to allow the mean velocity to be computed with fair precisio from the surface velocity observations.

SUBSURFACE OR DOUBLE FLOATS.

The double float consists of a small surface float connected by fine cord to a larger subsurface float, which is so arranged that i shall always remain at the point of mean velocity in the current. Th surface float may consist of a flat block of wood or a tin water-tigh drum, which floats upon the surface of the water with sufficient buoy ancy to prevent the larger subsurface float from sinking. Th subsurface float may consist of two sheets of galvanized iron set a right angles, weighted at the bottom, with an air-tight cylindrica device at the top, in order that it may at all times keep its vertica position. A round, hollow cylinder of tin also makes an excellen subsurface float. The tension on the connecting cord should be a least 2 or 3 pounds, and the cord should be of silk and as fine as pos sible in order that its resistance to the current should not have marked effect upon the velocity of the floats. The length of the cor

should be so regulated that the lower float may be at the point of mean velocity, and the resistance of the upper float and the cord should be made as small as practicable. A small flag should be placed upon the upper float in order that its position may be easily determined at all times. The chief objection to double floats is the uncertainty as to whether the cord is vertical and the consequent uncertainty as to the position of the subsurface float. Another objection is the modifying effect of the surface float and the cord upon the velocity of the lower float, as in great depth the exposed surface of the cord may exceed that of the float. A third objection is the uncertainty as to the vertical position of the lower float, as, owing to changes in depth of water and local conditions, the point of mean velocity may change, whereas the length of the connecting cord must remain constant in each run. This may introduce a noticeable error if the increase in depth is large, as the retarding effect of the slow velocity near the bottom of the river will not be felt by the float, and the result will show too high a velocity. The lower float may tip slightly, owing to eddies or other causes, thereby changing the exposed surface, or, unknown to the observer, the lower float may strike a bowlder, causing its velocity to be checked. In many cases these objections would not be at all serious, but, in general, when floats are to be used better results can be obtained, when the depth is not too great, by the use of rod or tube floats.

ROD OR TUBE FLOATS.

These consist of long, cylindrical tin tubes or wooden poles, 2 or 3 inches in diameter, weighted at the bottom, so that they will float vertically with only 2 or 3 inches exposed above the water surface. These rods integrate the velocities in a vertical section and give approximately the mean velocity of the current. It is important that they should extend nearly to the bottom, as otherwise the velocity, as shown, will be too great, yet the greatest care must be taken that they do not at any time scrape upon the rocks at the bottom or sides so as to retard their movement. Rod floats are free from many of the objections to double floats, as there is no uncertainty as to their position nor as to the point of mean velocity in the channel. They are not, however, suitable for very deep rivers, or for channels where the depth varies considerably, or where weeds grow in the bed of the stream. Mr. James B. Francis has stated that the rod floats travel a little faster than the mean velocity of the water even for the depth of immersion. The float will be subject to pressures proportional to the square of the relative velocities of the water at different points, and when it has attained its full speed there will be equilibrium between these different pressures. This equilibrium may exist, however, when the speed of the float is somewhat different from the mean velocity of the water, the latter being the arithmetical mean of all the different

velocities throughout the depth of immersion. The following formula for correcting an observed velocity was derived by James B. Francis from his Lowell experiments:

$$V_m = V_o\left[1 - .116\left(\sqrt{\frac{d-d'}{d}} - 0.1\right)\right]$$

Where V_m is equal to true mean velocity in vertical, V_o equals observed velocity of tube, d equals mean depth along path of tube, d' equals depth of immersion of tube.

Col. Allan Cunningham[a] has, however, calculated that such floats move somewhat slower than the water in which they are immersed. The error of assuming that the velocity of the tube represents the mean velocity in the vertical will not be material unless tubes too short are used, in which case the velocity as shown by the tube should be somewhat reduced.

WEIRS.

By the method of weirs the discharge of the stream is computed by means of an empirical formula, which varies for different types of dams or weirs. On creeks or small rivers it is sometimes practicable to build a timber weir across the channel, causing the total flow of the stream to pass over the sharp edge of the weir crest. By observing the head on the weir, computations of the flow can be made. This is probably the most accurate method applicable to small streams. On large rivers, however, the cost of a weir is usually so great as to be prohibitive, so that if there is not a weir or dam already in the stream it is necessary to resort to measurements by floats or current meters.

On many of the rivers of moderate size the conditions are unfavorable for successfully applying either of these methods. For instance, on streams used for manufacturing purposes dams occur at frequent intervals, interrupting the regular flow, and in many cases holding back the night flow for use during the following day, so that the discharge during the night may be either nothing or a very small percentage of the day flow. Then, too, the shutting down of the mill wheels for an hour at noon may have a pronounced effect upon the results of float or meter measurements made below the mill. Unfortunately these variations are not always apparent to the hydrographer, and surprise and annoyance are caused by finding that the river height differs by several tenths from the gage as read by the regular observer a short time before the hydrographer arrived at the station.

Under the conditions described, better results can undoubtedly be obtained if there exists upon the stream a good dam which can be used as a weir. It should have a level, even crest and a constant cross section, with sufficient pondage to reduce the velocity of approach, and it should be free from leakage. Masonry dams are better for

[a] Recent hydraulic experiments: Min. Proc. Inst. Civil Eng., Vol. LXXI 1883.

A. CURRENT METER IN USE, SUSPENDED FROM A BRIDGE.

B. CABLE AND CAR USED TO MEASURE DISCHARGE OF RIVER

this purpose, for they are more likely to be tight and to have an even crest. Timber dams, although level when first constructed, are likely to settle at various points, thus producing an uneven crest elevation. There are, however, many good timber dams practically free from leakage and with crests sufficiently uniform for accurate work.

Having selected a dam as the proper site for a station, a careful survey must be made of the crest line and of the upper and lower slopes, so that it can be compared with other dams or with experimental sections for which the coefficients of flow are known. The experiments of James B. Francis, of Fteley and Stearns, and of John R. Freeman, George W. Rafter, and others at Cornell University, have given coefficients upon many sections of various forms. It is probable that the dam selected for the station will not be exactly like any of the experimental forms, but it will resemble some of them so closely that coefficients can be selected for the computations.

When the mill gates are open a part of the flow is diverted from the river through the mill race, the gates, and the tailrace.

The amount of the diversion must of course be measured and added to the quantity flowing over the dam, in order to determine the total discharge of the stream. In many factories the quantity flowing through the wheels varies from day to day, and also during different hours of the day, so that careful records must be kept of gate openings, in order that proper allowance may be made for these variations. The size and the make of the water wheels must be ascertained, and the wheels be used as water meters for the determination of the flow through them. Many of the modern wheels have been carefully rated. Where such ratings have not been made, usually records of wheels of the same type, though possibly of different makes, can be found and the records be compared. Water wheels as meters give fairly accurate records of the discharge.

The Chezy formula or surface-slope method has been extensively employed in gaging large rivers. The proper coefficients to be applied are usually determined from the auxiliary formula of Gauguillet and Kutter. One difficulty in the application of this method lies in the selection of suitable friction factor or coefficient of roughness.

CURRENT METERS.

The current meter has been found best adapted to the general measurements made by the United States Geological Survey, and is used almost exclusively in its hydrographic investigations. (Pls. I and II.) Occasionally, however, either a meter is not available or the conditions are not favorable for its use. In such cases weirs or floats have been used, though a Pitot's tube, hydrometric pendulum, or hydrometric balance might in exceptional case be used to advantage.

The current meter has been described, and instructions for the care and use of the instrument have been given in Water-Supply Paper

No. 56. The object of the present discussion is to give a few ad tional facts as to the point at which the meter should be held determine the mean velocity in a channel, as deduced from me urements recently made upon rivers in the southern part of N York State. The current meter may be used to determine the vel ity of a river in four ways: First, by making point measureme at a depth corresponding to the approximate position of the thre of mean velocity; second, by deducing the mean velocity from ob vations made at other points in the same vertical; third, by t integration method; fourth, by point measurements made at regu intervals throughout cross sections of the river. In the first two these methods it is important to know the relation between the velo ties at various points in the section. In the first method the positi of mean velocity must be known, and in the second method t relation between the surface velocity, or the velocity at mean dep to the mean velocity must be known. In either of these cases t form of the vertical velocity curve will determine the coefficient to applied to the observations.

VERTICAL VELOCITY CURVES ON STREAMS WITHOUT I COVER.

Studies of the vertical velocity curve made on the Mississippi Riv by Humphreys and Abbott, on the Connecticut by T. G. Ellis, the Merrimac flume by Wheeler and Lynch, on the Potomac by C. Babb, and recent experiments by others, notably those at Corn University by E. C. Murphy, indicate that the point of mean veloc in a given vertical section is at a depth varying from six-tenths two-thirds of the total depth of the section, measured from the s face down. The values found in the experiments were as follows:

Depth from surface of point of mean velocity.

Experimenter.	Stream.	Dept
Cyrus C. Babb	Potomac River	0.
Humphreys and Abbott	Mississippi River	
T. G. Ellis	Connecticut River	
E. C. Murphy	Cornell flume	a
Wheeler and Lynch	Merrimac flume	

[a] For depths between 6 and 9 feet, the proportionate depth of point of mean velocity becom less as the depth of the water decreased, and becoming 0.55 for depths of water between 1 a feet.

The Cornell experiments indicate that measurements made at s tenths of the depth yield results 3.5 per cent too large, the depth

PRICE ELECTRIC CURRENT METERS.

mean velocity being nearly two-thirds of the depth. The measurements at Cornell were, however, made in the canal, the cross sections of which have a greater ratio of depth to width than most rivers, and decidedly more than the Mississippi, Connecticut, and Potomac, upon which the above coefficients were obtained. There can be no doubt but that the difference in the ratio of the depth to width is a factor likely to affect the position of mean velocity.

The bottom and sides of the channel retard the flow close to them in proportion to their roughness, this retardation being due more to the impeding of the flow by eddies than by friction alone. The retardation of the surface velocity has been attributed to the rising, by vertical motion, of the lower water to the surface after being checked in its flow by striking against the rough bottom and sides of the channel. The variation of the velocity in the river channel is shown in Pl. VIII (p. 30) and fig. 1.

Mr. Frederick P. Stearns has attributed the reduction of surface velocity to the general retarding of the layers of water adjacent to the banks of the stream, this water rising to the surface and thereby making the edges of the channel higher than the center and causing a flow of the slowly moving water from the sides toward the middle, thereby decreasing the surface velocity, depressing the point of maximum velocity, and lowering in general the filament of mean velocity. This depression of the maximum velocity is known to become more pronounced with an increase in the roughness of the lining, in the steepness of the banks, and in the ratio of depth to width. In an extreme case of a wide, shallow stream, where the bottom merges imperceptibly into the banks, maximum velocity occurs, under normal conditions, at or very near the surface of the center of the stream. On the other hand, in a deep, narrow channel, as for instance, in a canal with vertical sides, the maximum velocity occurs a considerable distance below the surface, and, as the Cornell experiments indicate, this depression may amount to as much as one-third and even two-fifths of the total depth. Evidently, then, in such cases depression of maximum velocity must result in a lowering of the thread of mean velocity, and engineers, in making unit measurements for mean velocity, should bear in mind that while the observations at six-tenths depth give fair values for mean velocity in wide, shallow rivers this ratio should be increased to two-thirds in the case of canals and flumes or narrow natural channels.

The friction of flowing water against the air has a similar influence, and, though in general less marked, it may, in the case of a strong upstream wind, have a decided influence upon the surface velocity and the point in the vertical of the maximum and mean velocity. On account of these resistances on the bed and bank of a stream, the maximum velocity of the river in a straight reach is found in the cen-

tral portion of the stream, and somewhat below the surface-actual position depending upon the size and condition of the and the velocity of flow. The velocity increases from the su downward for a short distance—say, one-tenth of the depth—and decreases down to the bottom, where it reaches the minimum.

Various writers who have studied the form and equation of curve representing the variation in velocities in a vertical section

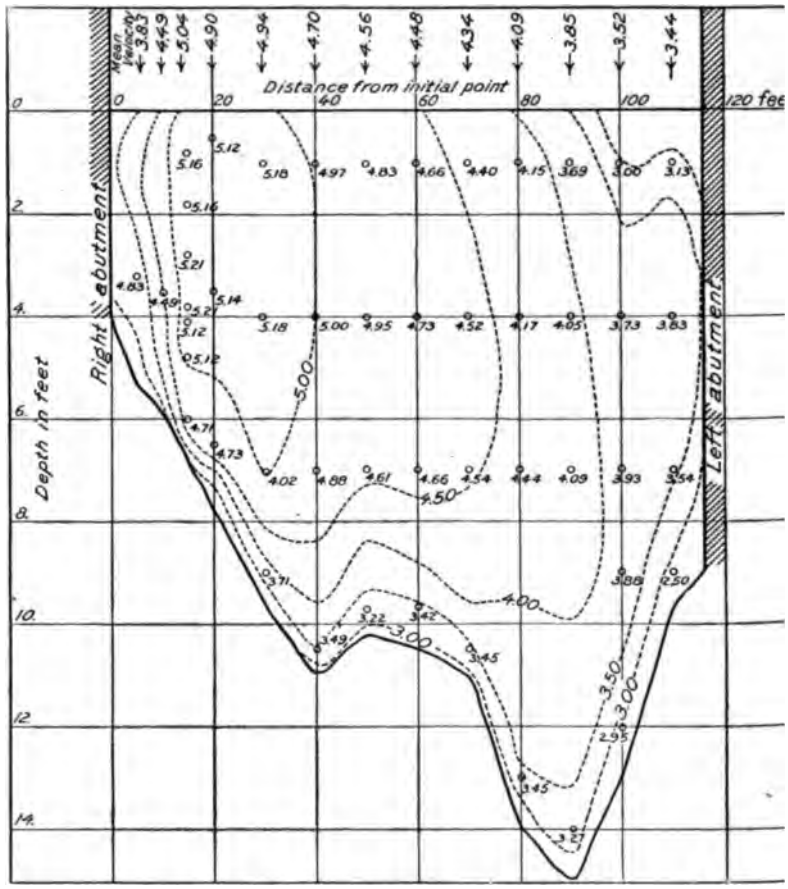


FIG. 1.—Cross section on Esopus Creek, at Kingston, showing curves of equal veloc determined by current-meter measurements, there being no ice cover.

come to different conclusions as to the form of this curve, the incl straight line, the parabola with horizontal axis, the parabola with tical axis and vertex at or below the surface, the ellipse, and the hy bola each having its advocates. Humphreys and Abbott showe their experiments on the Mississippi River that the curve did not fer materially from a parabola having its axis parallel to the su and at the depth below the surface of the position of maximum v

ity, the abscissas representing the velocities at the different depths and the ordinates the vertical distances of these depths from the point of mean maximum velocity. In the Mississippi River experiments the position of maximum velocity was on an average nearly one-third of the whole depth below the surface, varying with the direction of the wind. Bazin also found that the vertical velocity curve was in the form of a parabola, the curve varying with different channels and the position of maximum velocity. Professor von Wagner agreed with the above experimenters, but found that the curve differed from the parabola toward the bottom and near the surface, and that the point of maximum velocity varied from a little below the surface to a little over one-fourth of the full depth.

The exact mathematical form of a vertical velocity curve is not a vital question in the measurement of streams, but it is greatly to be desired that the relation between the surface, maximum, and mean velocities should be known, so that if any one of these be measured accurate computations of the flow can be made, and so that if the velocity of the stream be measured at some particular point the mean velocity of the whole section can be calculated. It has been shown by a series of measurements, the results of which are given herein, that the typical vertical velocity curve is in general of the form shown in fig. 2; that the surface velocity is somewhat greater than the mean; that the maximum velocity is below the surface but above mid depth; and that the point of mean velocity is from 0.6 to two-thirds of the depth below the surface. The relation between the surface velocity and the mean velocity is, of course, important in the use of surface floats and current meters when the velocity is measured only near the surface, for some coefficient must always be applied to obtain the mean velocity in the vertical section. In this connection, some results obtained by Mr. J. B. Lippincott on rivers in southern California, in April, 1902, are of interest:

On the Sacramento River, at Jellys Ferry, observations for velocities have been taken at the top, middle, and bottom of each section at intervals of 20 feet. The channel is of bowlders and has a depth of from 3 to 5 feet in the low-water stages. The relation of the mean velocity to the top velocity on each section was determined, and then the mean ratio for the entire measurement. The measurements were arranged in 6 groups according to gage heights. In the first group the mean velocity was 87 per cent of the surface velocity; in the second 88; in the third 88; in the fourth 89; in the fifth 87; in the sixth 87. The last group represents the highest water. The mean of 30 measurements gives a ratio of 88 per cent. In this case the coefficients are quite constant.

A determination on the Tuolumne River, at Lagrange, also gives a coefficient of 88 per cent. This river has a pebbly or stony bed, and the depths range from 1.12 to 1.84 feet. The velocities range from 3 to 5 feet.

On the smaller rivers the determinations were less satisfactory, because when depths become as low as 1 foot, top, middle, and bottom velocities were seldom observed with meters, and unless we had three observations for velocity the mean

velocity was not considered sufficiently accurate to justify a comparis the surface velocity.

The relative irregularities of the beds of the smaller streams also int wider ranges in the relation of surface to mean velocities.

On the San Gabriel River the following results were obtained at differer on the stream: 0.83, 0.94, 0.95, 0.89, 0.90, 0.98; mean, 0.92.

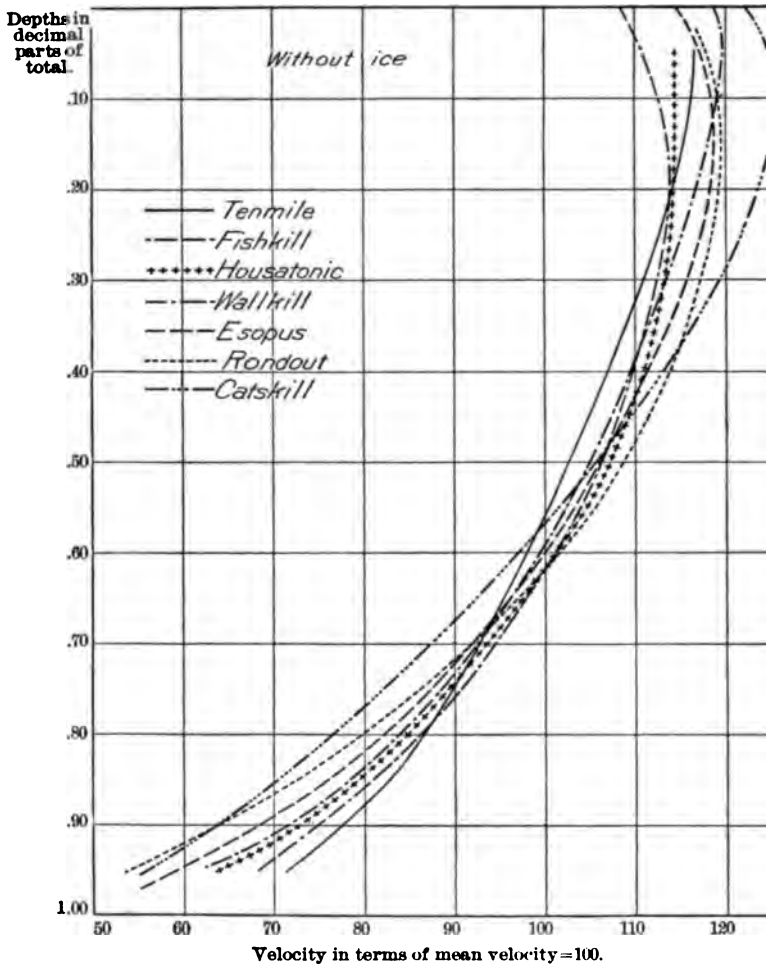
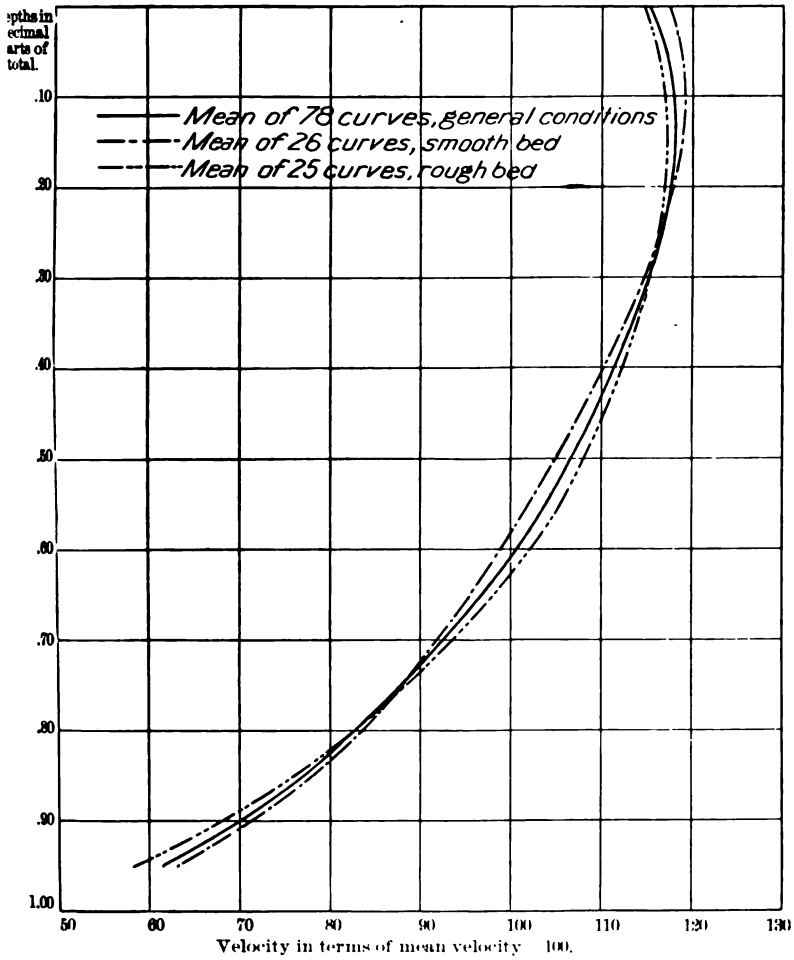


FIG. 2.—Mean vertical velocity curves for Esopus, Rondout, Catskill, and Fishkill and Wallkill, Tenmile, and Housatonic rivers.

On the Santa Ana River the following determinations were made at Springs: 0.96, 0.95, 0.91, 0.86, 0.90, 0.91, 0.96, 0.93; mean, 0.92.

The channels of these two streams are relatively rough, the water su usually from 10 to 20 feet in width, and the depths vary from 0.25 foot t for the stage of water observed upon. It is rather singular to note t determination of these coefficients in the smaller and relatively rough c shows a higher value than in the larger channels. As previously remark

er, the determinations for the San Gabriel and the Santa Ana are not considered entirely satisfactory nor as reliable as the determination for the Sacramento. is possible that the coefficients which we have determined for the smaller reams are too high, owing to the fact that the current meter could not be placed the slowest film of water immediately adjacent to the bottom and sides of the annel, so that the mean velocity as shown may be slightly above the true



G. 3.—Comparison of the general mean velocity curve with the mean curve for smooth bed and the mean curve for rough bed. (Note: The general mean curve includes all data obtained n 78 vertical velocity curves; the mean curve for rough bed includes the data for 25 vertical elocity curves, and the mean curve for smooth bed includes the data for 26 vertical velocity urves. All of these curves were taken when there was no ice cover.)

ean velocity. This error would be relatively greater in small than in large reams, however. In the measurements of the small stream a Price acoustic eter has been used, which permits the center of the meter to be placed within nches of the bed of the creek.

In consideration of the above data it is believed that for ordinary streams discharging 100 cubic feet per second of water, or less, on stony beds, that 0.9 of the

mean surface velocity for the section will represent the mean velocity for the section, said surface velocities being observed at numerous points across the stream.

[a] With the object of determining the ratio between the maximum surface velocities and the mean velocity, De Prony made some experiments in wooden troughs, and Messrs. Baldwin, Whistler, and Slosson in channels lined with planks. The coefficients obtained for converting the observed surface velocity into mean velocity were 0.816 by De Prony and from 0.810 to 0.847 by the latter observers in different channels. Subsequent experiments indicate that the coefficient is generally comprised within the limits of 0.8 and 0.9, depending upon the size of the channel and the nature of the bed. The Mississippi River experiments show the coefficients to exceed 0.9, but it is quite possible that the influence of the long connecting cord and surface float caused too large values to be recorded for the velocities toward the bottom and thus gave too high a value to the mean velocity, as Mr. Robert Gordon, in checking his experiments on the Irrawaddi with a current meter, obtained considerable reduction in the velocities approaching the bottom compared with those obtained by double floats. The coefficient would be greatest for large, deep rivers with smooth, uniform channels, and least for small, shallow streams with rough beds. Messrs. Darcy and Bazin derived from their experiments the following formula giving the relation between the maximum velocity and the mean velocity:

$$U-V=25.36\sqrt{R\,S}$$

where U is the maximum velocity in feet per second, V the mean velocity, R the hydraulic radius in feet, and S the slope.

The variation in the coefficient to be applied to the surface velocity gives rise to a possible error large enough to preclude the use of this method of measurement when accurate results are desired. As a quick method it may often be used, and in a few cases, as, for instance, at the time of high floods, when it is impossible to use other means the results obtained by this method may be of considerable value.

The mean of 78 velocity curves taken upon rivers in the southern part of New York State, described further on in this paper, shows that the mean velocity was 0.87 of the surface velocity in the vertical section (shown in fig. 3). This coefficient varied from 0.82 in the case of Catskill Creek to 0.93 on Fishkill Creek (fig. 2). It will be noted that these coefficients apply to the mean velocity in the vertical in which the float is run. If only one surface float is used, and that in the center of the river, or point of maximum velocity, it appears that 0.8 is the proper coefficient to apply, though the chances of error are much greater than when surface floats are used at intervals across the channel.

[a] From Rivers and Canals, vol. 1, p. 38, by L. F. Vernon-Harcourt.

GAGING STATION ON CATSKILL CREEK AT SOUTH CAIRO, N. Y.

GAGING STATION ON ESOPUS CREEK AT KINGSTON, N. Y.

GAGING STATION ON WALLKILL RIVER AT NEW PALTZ, N. Y.

RIVER STATIONS AT WHICH CURVES WERE OBTAINED.

In June, 1901, a reconnaissance was made of Catskill, Esopus, and Rondout creeks, and Wallkill River west of the Hudson, and Fishkill Creek and Tenmile and Housatonic rivers east of the Hudson. Nearly the entire length of each stream was traversed, and a site for a gaging station selected on each. Early in July the stations were established, with the exception of that on Tenmile River, which was established in September of the same year. Persons living near at hand were employed as gage readers to take observations of the stage of the stream twice each day. Mr. A. E. Place was in charge of these stations until September, 1901, when Mr. W. W. Schlecht was placed in charge as resident hydrographer. The measurements given in this paper were obtained by Messrs. Place and Schlecht, and the tables and several of the diagrams were prepared by Mr. Schlecht. The object of the measurements made at these stations was to determine primarily the run-off from the various drainage basins and the availability of the streams as sources of additional supply of water for New York City. The results of the measurements, together with the heights of water in the river on each day, have been published in Water-Supply Paper No. 65. Incidentally it was thought best to make observations as to the point of mean velocity in each of these streams for use in future measurements on the same rivers, as well as for general information as to the most desirable method of making current-meter measurements on rivers in general. In making measurements of rivers of this character it has been the custom of the Hydrographic Division of the United States Geological Survey to divide the cross section into partial areas of regular width, say 5 or 10 feet, and to determine the velocity in each of these small areas by holding the meter at a point six-tenths of the total depth below the surface. The velocity obtained at this point was assumed to be the mean velocity in the small area in which the meter was used. It was realized that this relation would not hold true in all streams, but in rivers with the general characteristics of those under discussion it was considered that no serious error would result from this assumption. The data in the following pages were collected in order to check the above assumption or to enable the hydrographer to determine by a point measurement the velocity at some other depth which might be considered the mean in the channel. Each of the stations established will now be briefly described. The drainage basins were described in detail in Water-Supply Paper No. 65.

CATSKILL CREEK AT SOUTH CAIRO, N. Y.

The gaging station is located at the highway bridge in the village of South Cairo, a view of which is shown on Pl. III. The total span

of the bridge is 194.5 feet between abutments, the faces of whic vertical. The stream bed is of earth for 25 feet from the right ment. At this point the bluestone rock ledge outcrops, covered patches of loose shingle and shifting gravel, while the left side c channel is covered with small gravel. The entire flow of the st at all stages passes under this bridge. High-water marks at the b indicate a maximum elevation of 17.5 feet on the gage. The sta the stream is observed each morning and evening by the local reader, and current-meter measurements are made at intervals b resident hydrographer.

ESOPUS CREEK AT KINGSTON, N. Y.

This gaging station was established at Washington avenue b in Kingston July 5, 1901, a view of which is shown in Pl. IV. bridge has a clear span of 106.6 feet between abutments, whic nearly vertical. In addition there is on the left side a channel 1 in width through which water passes at high stages of the river. readings are made here each morning and evening. The bed is co with small stone over part of the channel, the rest of the bed made up of sand, silt, and small gravel.

WALLKILL RIVER AT NEW PALTZ, N. Y.

A gaging station is situated at the New Paltz highway bridge, a of which is given in Pl. V. The bridge is a span of 146.6 feet bet the vertical faces of the masonry abutments. The entire flow p under this bridge except in extreme freshets, when the left ba overflowed.

The bed of the river is for the most part smooth, and compos sand and silt.

RONDOUT CREEK AT ROSENDALE, N. Y.

A gaging station was established at the highway bridge at Rosen 3 miles above the junction of the Wallkill, July 6, 1901. The b is a single span of 136 feet, and is shown in Pl. VI. The bed c channel is rock with bowlders for 40 feet from right bank, the r the bed being covered with broken rock from 6 inches to 1 fo diameter. The entire flow, aside from the diversion to the Del and Hudson Canal, passes under the bridge at all stages.

FISHKILL CREEK AT GLENHAM, N. Y.

A gaging station is located at the Newburg, Dutchess and necticut Railroad bridge, in Glenham. It was established Ju 1901. The bridge consists of the main central span with two

GAGING STATION ON RONDOUT CREEK AT ROSENDALE, N. Y.

GAGING STATION ON HOUSATONIC RIVER AT GAYLORDSVILLE, CONN.

ary overflow channels at the ends, the length of span being as follows: Left overflow, station zero to 22.5; main span, station 27.5 to station 122; right overflow, station 127 to station 149. The bed of the main channel is earth and gravel; that of the overflow channels is broken stone.

TENMILE RIVER BELOW DOVER PLAINS, N. Y.

A gaging station was established September 16, 1901, at Tabor's bridge, which crosses Tenmile River about 2,000 feet below the point of inflow of Swamp River. The gaging station is situated about 2 miles below Dover Plains Village. Tabor's bridge consists of a single span, 85 feet between abutments. The bridge stands square across the stream, the bed of which is sand and gravel. The entire flow passes between the abutments of this bridge, except at the time of extreme high water, which occurs nearly every spring when the river overflows its banks, and some water passes around one end of the bridge.

HOUSATONIC RIVER AT GAYLORDSVILLE, CONN.

A gaging station was established at Gaylordsville, Conn., October 24, 1900. The station is situated 3 miles east of the New York State line and 2 miles below the mouth of Tenmile River. Owing to the unfavorable conditions under the bridge, the discharge measurements are made from a cable of 200 feet span placed across the stream 1¼ miles below the bridge. A view of the river at this point is shown in Pl. VII. The cable is supported on the right bank by timber shears 25 feet high and is anchored to a large buried rock. On the left bank a sycamore tree serves as a support for the cable, which is anchored to the base of a large oak.

DISCUSSION OF TABLES.

In the tables that are given in the following pages the measurements recorded were taken at the time of the regular gagings of the rivers, and with the same degree of accuracy with which current-meter measurements have been made upon these streams. Only one instrument was used at one time, the velocity being taken at the various points in regular order vertically, usually at intervals of one-half foot. When other space intervals were used it is shown in the tables.

In Pl. VIII is shown the variation in the velocity of Wallkill River at New Paltz. The dotted lines are lines of equal velocities and are determined by observations of velocity at regular intervals throughout

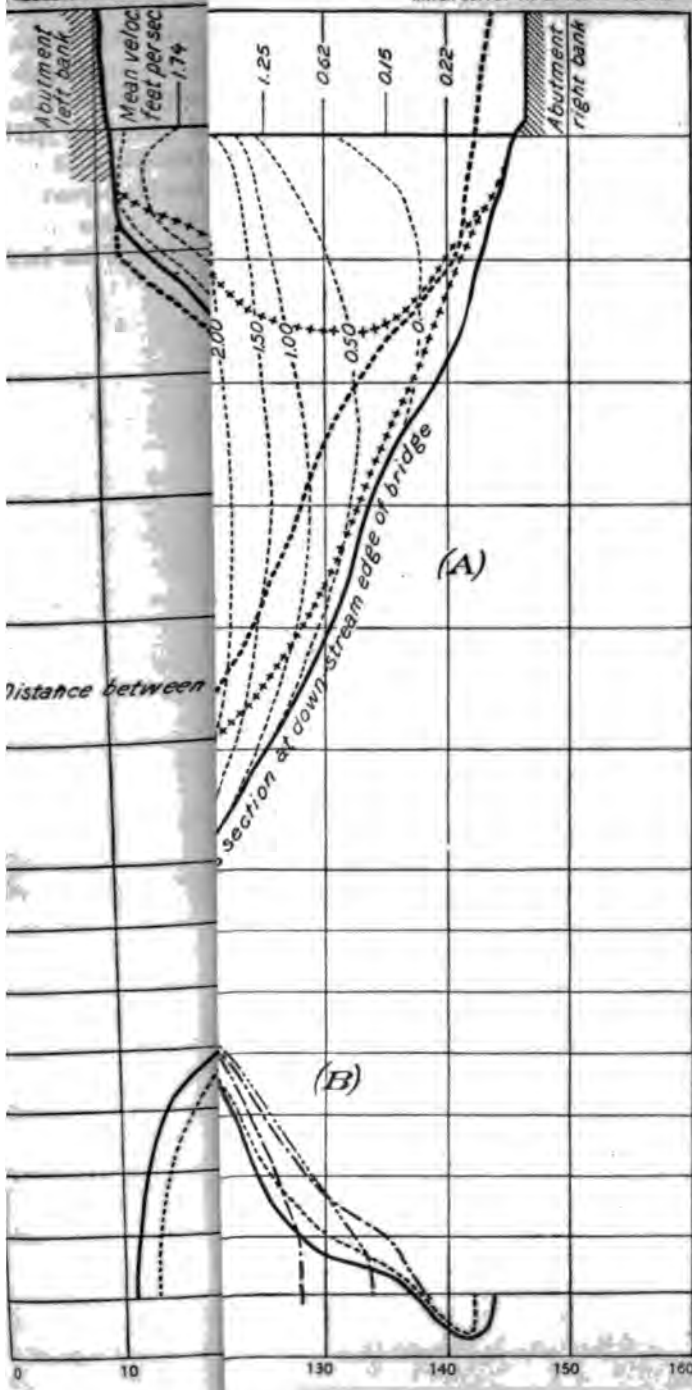
the cross section. The line marked "mean velocity for each section" shows the depth at which may be found the filament of mean velocity. Near the right bank there is slack water and some return current, which accounts for the peculiar position of the curve, and the fact that there are two lines of mean velocity. This condition would not usually occur at a gaging station.

At the bottom of Pl. VIII are lines showing the velocity at various depths, as 1 foot, 2 feet, etc., across the river section. The effect of the ledge of rocks is clearly shown in the plate.

A small Price current meter was used, and was in each case suspended from a bridge and hung freely in the water. The meter was held fifty seconds at one point to determine the velocity, and in each case the first reading was checked by a second, and if there was a discrepancy a third reading was taken. The results were plotted upon cross-section paper, the depths as ordinates and the velocities as abscissas, and a smooth curve drawn through the points, so that in case there was an error of sufficient magnitude to affect the final results it would be found when the curve was plotted. Before the work was commenced, and after the completion of these curves, the meter was rated and showed very slight change in its readings. The gage height was read at the beginning of each measurement and at its completion, and in general no change of stage of the stream during the measurement was noted.

In Table I the date of each measurement is given at the head of the column, then the point of measurement—that is, the distance in feet from the initial point of soundings which had been previously established and marked permanently on the bridge. Next is given the gage height at the time the velocities were measured and the depth of water at the point of measurement at the time of making the measurement. The character of the bed of the river and the force and direction of the wind are also given. The depths, as given in the alternate columns, were measured by a wire attached to the meter and a tape. The column headed "Velocities" gives the actual observed velocity in feet per second at each observation.

Table II is computed from Table I, the observations being the same, but the velocities being given at regular depths as shown in percentages of the whole in the first column. The velocities as shown in the columns of this table were found from the plotted vertical velocity curves based upon the figures in Table I, the velocities at each depth being taken by scale directly from the curve. The sum of the velocities in each column of Table II divided by 10 gives the mean velocity in that section, and is the quantity that should be obtained by a single meter observation at a point in the section which represents the point of mean velocity. For comparison, the velocity as actually found at six-tenths of the depth is given at the bottom of Table II, from which



A. CROSS SECTIONS; B. HORIZONTAL VELOCITY CURVES ON A.

it will at once be seen that the error in measuring the velocity at six-tenths depth is in general only slight on a stream of the general character of the Esopus.

Tables III, V, VII, IX, XI, and XIII show the results of the measurements on the Rondout, Wallkill, Catskill, Fishkill, Tenmile, and Housatonic, respectively; Tables IV, VI, VIII, X, XII, and XIV show the data obtained from the preceding tables, and were derived by the same method as Table II from Table I.

TABLE I.—*Velocities in vertical sections on Esopus Creek at Kingston.*

Date	July 19.		Aug. 10.		Aug. 19.		Aug. 29.		Aug. 29.		Aug. 29.		Sept. 6.		Sept. 6.		Sept. 21.		Sept. 26.	
Point of measurement	90.		90.		95.		75.		80.		90.		40.		80.		90.		85.	
Gage height	4.40.		4.85.		4.60.		5.50.		5.50.		5.50.		5.46.		5.46.		4.78.		4.55.	
Depth	6.4.		6.2.		5.7.		4.4.		6.1.		7.2.		2.6.		5.3.		6.6.		5.6.	
Bed of river	Silt and gravel		Silt and gravel.		Silt and sand.		Bowlders.		Bowlders.		Silt and gravel.		Bowlders.		Bowlders.		Silt and gravel.		Bowlders.	
Wind force	Strong.		Gentle.		Light.		Gentle.		Gentle.		Gentle.		None.		None.		Gentle.		Gentle.	
Direction of wind	Upstream.		Downstream.		Upstream.		Downstream.		Downstream.		Downstream.						Upstream.		Downstream.	
	Depth	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
	0.4	0.77	0.2	1.03	0.2	0.82	0.2	1.44	0.2	1.42	0.2	1.31	0.2	1.40	0.2	1.44	0.5	0.85	0.5	0.86
	.9	.77	.7	1.00	.7	.89	.7	1.45	.7	1.54	.7	1.38	.7	1.35	.7	1.47	1.0	.87	1.0	.84
	1.4	.73	1.2	1.03	1.2	.82	1.2	1.38	1.2	1.52	1.7	1.35	1.2	1.07	1.2	1.40	1.5	.87	1.5	.80
	1.9	.71	1.7	1.05	1.7	.86	1.7	1.29	1.7	1.42	2.7	1.24	1.7	1.07	1.7	1.40	2.0	.95	2.0	.85
	2.4	.70	2.2	1.00	2.2	.86	2.2	1.31	2.7	1.40	3.7	1.17	2.1	.96	2.2	1.40	2.5	.85	2.5	.80
	2.9	.66	2.7	.98	2.7	.82	2.7	1.19	3.7	1.05	4.7	.91	.....	.....	2.7	1.38	3.0	.86	3.0	.77
	3.4	.61	3.2	.91	3.2	.75	3.2	1.05	4.7	1.24	5.7	.94	.....	.....	3.7	1.20	3.5	.87	3.4	.75
	3.9	.57	3.7	.86	3.7	.68	3.7	.89	5.6	1.05	6.2	.75	.....	.....	4.2	1.16	4.0	.78	3.5	.72
	4.4	.57	4.2	.77	4.2	.67	3.9	.68	.....	.....	.....	.....	.....	.....	.....	.....	4.5	.70	4.0	.75
	4.9	.48	4.7	.75	4.7	.65	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.0	.65	4.5	.68
	5.4	.54	5.2	.68	5.2	.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.5	.48	5.1	.47
	5.9	.54	5.7	.63	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.1	.40	.....	.....

Date	Oct. 16.	Oct. 16.	Oct. 21.	Nov. 1.	Nov. 3.	Nov. 18.	Nov. 18.	Nov. 20.	Nov. 20.
Point of measurement	40.	90.	90.	80.	95.	77.	87.	85.	90.
Gage height	6.64.	6.64.	5.56.	4.74.	4.74.	4.45.	4.45.	5.06.	5.06.
Depth	4.0.	8.6.	7.4.	5.0.	5.9.	4.4.	5.0.	6.0.	6.8.
Bed of river	Bowlders.	Silt and gravel.	Silt and gravel.	Bowlders.	Silt and sand.	Bowlders.	Silt and gravel.	Silt.	Silt and gravel.
Wind force	None.	None.	Gentle.	None.	None.	Gentle.	Gentle.	Gale.	Gale.
Direction of wind			Upstream.			Upstream.	Upstream.	Down-stream.	Down-stream.

Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
0.5	2.38	0.5	1.80	0.5	1.42	0.5	0.88	0.5	0.85	0.5	0.80	0.8	0.67	0.5	0.97	0.5	1.04
1.5	2.29	1.5	1.80	1.5	1.37	3	.92	1.5	.82	1.5	.80	.8	.70	1.5	.97	1.5	1.05
2.4	2.12	2.5	1.66	2.5	1.32	2.5	.91	2.5	.71	2.5	.77	1.7	.67	2.5	.84	2.5	.91
2.5	2.07	3.5	1.79	3.5	1.22	3.0	.91	3.5	.67	2.6	.76	2.7	.57	3.6	.80	4.1	.82
3.0	1.52	4.5	1.74	4.4	1.10	3.5	.87	3.5	.60	3.5	.80	3.0	.52	4.5	.70	5.0	.67
3.5	1.25	5.2	1.65	4.5	1.07	4.5	.80	4.5	.62	3.8	.46	3.7	.51	5.5	.60	6.8	.51
.....	.....	5.5	1.57	5.5	.97	.....	.....	5.4	.42	5.5	.47	4.5	.27	.....	.....	.....	.....
.....	.....	6.5	1.42	6.5	.85	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	7.5	1.22	7.0	.72	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	8.1	1.15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE II.—*Velocities at regular intervals in vertical sections on Esopus Creek, deduced from data in Table I.*

[Velocities in feet per second.]

Depth in parts of total.	July 19.	Aug. 10.	Aug. 19.	Aug. 29.	Aug. 29.	Aug. 29.	Sept. 6.	Sept. 6.	Sept. 21.	Sept. 26.	Oct. 16.	Oct. 16.	Oct. 21.	Nov. 1.	Nov. 1.	Nov. 18.	Nov. 18.	Nov. 18.	Nov. 26.	Nov. 26.
0.05	0.77	1.02	0.83	1.45	1.48	1.34	1.40	1.45	0.85	0.83	2.24	1.88	1.41	0.97	0.84	0.85	0.79	0.67	0.97	1.06
.15	.76	1.04	.87	1.44	1.51	1.38	1.38	1.46	.88	.84	2.28	1.89	1.42	.97	.85	.85	.82	.70	.98	1.04
.25	.74	1.05	.87	1.41	1.47	1.35	1.35	1.44	.90	.85	2.30	1.87	1.37	.96	.82	.84	.81	.69	.95	1.01
.35	.71	1.02	.85	1.36	1.42	1.29	1.29	1.42	.89	.83	2.29	1.84	1.30	.94	.78	.82	.78	.67	.92	.97
.45	.68	.96	.82	1.29	1.37	1.21	1.22	1.40	.86	.81	2.26	1.77	1.23	.92	.74	.80	.74	.63	.87	.92
.55	.64	.90	.77	1.22	1.30	1.13	1.04	1.37	.81	.78	2.17	1.68	1.15	.90	.68	.77	.69	.58	.92	.86
.65	.60	.83	.72	1.14	1.22	1.04	1.06	1.32	.73	.74	2.00	1.56	06	.87	.63	.73	.64	.52	.77	.71
.75	.56	.76	.66	1.02	1.14	.94	.98	1.25	.63	.68	1.70	1.44	96	.83	.57	.66	.58	.44	.72	.62
.85	.52	.68	.60	.85	1.05	.83	.89	1.17	.48	.58	1.39	1.29	85	.69	.49	.54	.52	.35	.65	.58
.95	.43	.60	.51	.56	.94	.69	.79	1.02	.27	.36	.97	1.08	.65	.45	.40	.34	.43	.25	.55	.45
Mean	.64	.89	.75	1.17	1.29	1.12	1.15	1.33	.73	.73	1.96	1.63	1.14	.85	.68	.72	.68	.55	.82	.83
.60	.63	.87	.75	1.18	1.26	1.09	1.11	1.34	.77	.76	2.08	1.63	1.11	.88	.66	.75	.67	.55	.80	.81

Character of the bed: From station 0 to 86 broken rock from 0.5 feet to 1.0 foot in diameter. From station 86 to 105 smooth and even bed, composed of sand, silt, and small gravel. From 105 to 116 broken rock 0.5 feet to 1.0 foot in diameter.

TABLE III.—*Velocities in vertical sections on Rondout Creek at Rosendale.*

Date	Aug. 8.		Aug. 8.		Aug. 8.		Sept. 4.		Sept. 24		Oct. 11.		Oct. 11.		Oct. 11.		Oct. 18.		Nov. 7.		Nov. 16.		Nov. 28.		Dec. 21.	
Point of measurement	90.		105.		45.		85.		75.		65.		75.		85.		65.		80.		70.		65.		70.	
Gage height	7.50.		7.50.		7.15.		7.55.		6.45.		6.47.		6.47.		6.47.		7.08.		6.42.		6.55.		7.21.		7.60.	
Depth	7.2.		5.9.		5.2.		4.7.		5.6.		5.6.		5.6.		6.2.		6.3.		6.2.		5.6.		6.6.		6.4.	
Bed of creek	Bowlders.		Bowlders.		Bowlders.		Rock.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.	
Wind force	None.		None.		None.		Gentle.		Gentle.		Gentle.		Gentle.		Gentle.		Strong.		Gentle.		Strong.		None.		Gentle.	
Direction of wind							Down-stream.		Down-stream.		Up-stream.		Up-stream.		Up-stream.		Down-stream.		Up-stream.		Down-stream.				Up-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*
	0.2	1.70	0.2	1.33	0.2	1.29	0.2	1.58	0.3	0.51	0.5	0.55	0.5	0.60	0.8	0.52	0.3	1.41	0.5	0.48	0.5	0.65	0.5	7.76	3.5	1.94
	.7	1.60	1.2	1.42	.7	1.40	1.2	1.52	1.0	.52	1.5	.52	1.5	.55	1.8	.50	.5	1.42	1.5	.46	1.5	.65	1.5	1.71	1.5	1.96
	1.2	1.65	2.2	1.22	1.2	1.42	2.2	1.49	2.0	.50	2.5	.52	2.5	.47	2.8	.50	1.5	1.42	2.5	.45	2.5	.60	2.5	1.70	2.5	1.89
	2.2	1.54	3.2	1.24	1.7	1.44	3.2	1.44	3.0	.47	3.4	.45	3.4	.47	3.7	.45	2.5	1.37	3.5	.43	3.4	.56	3.5	1.69	3.5	1.77
	3.2	1.33	4.2	1.05	2.2	1.40	4.2	1.19	3.4	.46	3.5	.40	3.5	.42	3.7	.45	3.5	1.35	3.7	.45	3.5	.50	4.0	1.70	3.8	1.70
	4.0	1.29	5.2	.75	3.2	1.14			4.0	.43	4.5	.32	4.3	.35	4.7	.40	3.8	1.22	4.6	.32	4.5	.32	5.0	1.30	4.5	1.50
	4.2	1.24			4.2	.89			5.1	.30	5.1	.37	5.1	.25	5.7	.22	4.5	1.07	5.6	.20	5.0	.20	4.0	1.04	5.5	.80
	5.2	1.00															5.5	.82							5.9	.62
	6.2	.98															5.8	5.2								
	6.7	.86																								

TABLE IV.—*Velocities at regular intervals in vertical sections on Rondout Creek at Rosendale, deduced from data in Table III.*

[Velocities in feet per second.]

Depth in parts of total.	Aug. 8.	Aug. 8.	Aug. 8.	Sept. 4.	Sept. 24.	Oct. 11.	Oct. 11.	Oct. 11.	Oct. 18.	Nov. 7.	Nov. 16.	Nov. 26.	Dec. 21.
0.05	1.65	1.36	1.33	1.57	0.51	0.55	0.58	0.50	1.41	0.46	0.65	1.75	1.93
.15	1.66	1.39	1.40	1.57	.52	.55	.57	.52	1.42	.47	.65	1.76	1.97
.25	1.59	1.37	1.43	1.55	.52	.54	.56	.51	1.41	.47	.65	1.75	1.96
.35	1.50	1.34	1.40	1.53	.51	.52	.54	.50	1.40	.47	.63	1.73	1.93
.45	1.40	1.28	1.33	1.50	.49	.50	.52	.49	1.37	.46	.60	1.70	1.86
.55	1.29	1.21	1.23	1.47	.47	.46	.48	.47	1.30	.43	.55	1.66	1.77
.65	1.18	1.11	1.10	1.42	.44	.41	.44	.43	1.20	.39	.49	1.53	1.60
.75	1.07	.99	.97	1.35	.40	.36	.37	.39	1.08	.34	.39	1.37	1.35
.85	.95	.82	.83	1.28	.34	.30	.29	.32	.92	.28	.28	1.17	1.02
.95	.81	.63	.68	1.16	.26	.21	.20	.17	.59	.18	.17	.88	.61
Mean	1.31	1.15	1.17	1.44	.44	.44	.45	.43	1.21	.40	.51	1.53	1.60
.60	1.24	1.16	1.17	1.45	.46	.44	.46	.45	1.25	.41	.52	1.60	1.69

Character of bed: From station 0 to 40, rock bed with some bowlders; from station 40 to bank, broken rock from 0.5′ to 1′ in diameter.

TABLE V.—VELOCITIES IN DIFFERENT SECTIONS OF A CHANNEL ACROSS THE [illegible]

Date	Aug. 10.		Oct. 1.		Oct. 9.		Oct. 24.		Oct. 24.		Nov. 9.		Nov. 16.		Nov. 16.		Nov. 16.	
Point of measurement	70.		70.		105.		80.		105.		90.		105.		90.		80.	
Gage height	10.0.		7.36.		6.48.		6.33.		6.33.		5.94.		6.50.		6.50.		6.50.	
Depth	9.8.		7.5.		7.8.		6.4.		7.6.		6.2.		7.8.		6.6.		6.4.	
Bed of river	Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.	
Wind force	Gentle.		Gentle.		Fresh.		Fresh.		Fresh.		Gentle.		Fresh.		Fresh.		Fresh.	
Direction	Downstream.		Downstream.		Downstream.		Upstream.		Upstream.		Downstream.		Downstream.		Downstream.		Downstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.3	3.00	0.3	1.79	0.5	1.22	0.3	0.89	0.5	0.95	0.5	0.62	0.5	1.21	0.5	1.20	0.5	1.16
	1.0	3.05	1.3	1.70	1.5	1.15	0.8	.91	1.5	.97	1.5	.55	1.5	1.11	1.5	1.17	2.0	1.05
	2.0	2.77	2.3	1.67	2.5	1.12	1.5	.86	2.5	.92	2.5	.50	2.5	1.05	2.5	1.05	3.0	.92
	3.0	2.91	3.3	1.60	3.5	1.12	2.5	.77	3.5	.95	3.5	.42	3.5	1.05	3.5	.89	3.8	.90
	4.0	2.86	4.3	1.50	4.5	1.08	3.5	.70	4.5	.92	3.7	.48	4.5	1.05	4.0	.91	5.0	.72
	5.0	2.86	4.5	1.52	4.7	1.05	3.8	.75	4.6	.92	4.5	.30	4.7	1.07	4.5	.81	5.9	.66
	6.0	2.58	5.3	1.40	5.5	.97	4.5	.65	5.5	.82	5.7	.26	5.5	.91	5.5	.62	.....	.....
	7.0	2.47	6.3	1.32	6.5	.87	5.5	.47	6.5	.73	.....	.....	6.5	.80	6.1	.54	.....	.....
	8.0	2.35	6.9	1.15	7.3	.50	5.8	.37	7.1	.60	.....	.....	7.3	.60	.....	.....	.....	.....
	9.0	1.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE VI.—*Velocities at regular intervals in vertical sections on Wallkill River at New Paltz, deduced from data in Table V.*

[Velocities in feet per second.]

Depth in parts of total.	Aug. 20.	Oct. 1.	Oct. 9.	Oct. 24.	Oct. 24.	Nov. 9.	Nov. 16.	Nov. 16.	Nov. 16.
0.05	3.00	1.77	1.23	0.90	0.94	0.62	1.20	1.20	1.16
.15	3.04	1.75	1.18	.90	.97	.59	1.15	1.18	1.13
.25	2.99	1.70	1.14	.87	.97	.56	1.13	1.15	1.08
.35	2.91	1.65	1.12	.83	.96	.53	1.10	1.08	1.08
.45	2.82	1.59	1.10	.79	.94	.49	1.07	1.01	.97
.55	2.72	1.52	1.07	.75	.92	.45	1.02	.98	.91
.65	2.60	1.45	1.03	.69	.86	.40	.97	.93	.84
.75	2.44	1.37	.95	.63	.80	.35	.90	.78	.77
.85	2.20	1.27	.82	.53	.71	.30	.77	.61	.68
.95	1.88	1.13	.46	.35	.53	.24	.49	.48	.58
Mean	2.66	1.52	1.01	.724	.86	.453	.98	.92	.91
.60	2.66	1.49	1.05	.72	.89	.43	1.00	.88	.88

Character of bed of stream: At all of the above stations the bed of the creek is smooth, composed of sand and silt.

TABLE VII.—*Velocities in vertical sections on Catskill Creek at South Cairo.*

Date	July 20		July 25		July 25		Aug. 1.		Aug. 1.		Aug. 9.		Aug. 23.		Sept. 2.		Sept. 2.		Sept. 7.		Sept. 23.		Oct. 22.		Nov. 8.		Sept. 2.	
Point of measurement	55.		55.		45.		55.		60.		50.		60.		35.		40.		35.		55.		30.		50.		60.	
Gage height	3.60.		3.00.		3.00.		2.80.		2.80.		3.00.		3.12.		3.00.		3.00.		2.92.		2.74.		2.82.		2.70.		3.00.	
Depth	3.6.		2.9.		3.6.		2.7.		2.7.		3.1.		2.9.		4.4.		3.9.		4.3.		2.7.		2.3.		2.9.		3.0.	
Bed of creek	Rock.		Rock.		Rock.		Rock.		Gravel.		Rock.		Gravel.		Gravel.		Gravel.		Rock.		Gravel.		Rock.		Rock.		Gravel.	
Wind force	None.		Gentle.		Gentle.		Strong.		Strong.		Gentle.		Gentle.		Gentle.		Gentle.		.....		.....		.....		Fresh.		Gentle.	
Direction	.....		Down-stream.		Down-stream.		Down-stream.		Down-stream.		Up-stream.		Down-stream.		Up-stream.		Up-stream.		None.		None.		None.		Down-stream.		Up-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.2	1.67	0.2	0.75	0.2	0.66	0.2	0.52	0.2	0.48	0.2	0.61	0.3	1.05	0.2	0.61	0.2	0.73	0.2	0.48	0.2	0.48	0.2	0.37	0.5	0.37	0.2	0.77
	.5	1.72	.5	.77	.5	.63	.5	.50	.5	.48	.7	.67	.8	1.03	.7	.59	.7	.71	.7	.50	.7	.42	.7	.36	1.0	.35	.6	.75
	1.0	1.54	1.0	.75	1.0	.66	1.0	.45	1.0	.43	1.2	.66	1.3	.99	1.2	.52	1.2	.69	1.2	.41	1.2	.35	1.2	.32	1.5	.30	1.1	.78
	1.5	1.52	1.5	.63	1.5	.57	1.5	.43	1.5	.36	1.7	.59	1.8	.73	1.7	.50	1.7	.61	1.7	.43	1.6	.35	1.4	.31	1.7	.31	1.6	.54
	2.0	1.47	1.7	.59	2.0	.57	1.6	.43	1.6	.38	2.0	.50	2.3	.57	2.2	.43	2.2	.63	2.7	.29	1.7	.25	1.8	.27	2.0	.28	2.1	.54
	2.5	1.21	2.0	.52	2.2	.61	2.0	.36	2.0	.25	2.2	.54	2.8	.34	2.7	.38	2.7	.61	3.8	.23	2.2	.17	.....	.....	2.4	.25	2.6	.36
	3.0	1.07	2.4	.45	2.5	.50	2.2	.25	2.2	.25	2.7	.54	.....	.....	3.2	.29	3.2	.58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3.1	1.13	.....	.....	3.0	.50	.....	.....	.....	.....	.....	.....	.....	.....	3.7	.22	3.7	.52	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE VIII.—*Velocities at regular intervals in vertical sections on Catskill Creek at South Cairo, deduced from data in Table VII.*

[Velocities in feet per second.]

Depth in parts of total.	July 20.	July 25.	July 25.	Aug. 1.	Aug. 1.	Aug. 9.	Aug. 23.	Sept. 2.	Sept. 2.	Sept. 7.	Sept. 28.	Oct. 22.	Nov. 8.	Sept. 2.
0.05	1.69	0.75	0.64	0.52	0.48	0.65	1.06	0.60	0.72	0.48	0.47	0.37	0.37	0.77
.15	1.70	.76	.65	.51	.49	.68	1.05	.59	.71	.49	.44	.38	.37	.76
.25	1.65	.76	.65	.50	.47	.68	1.03	.56	.70	.46	.41	.37	.36	.75
.35	1.58	.73	.63	.48	.44	.67	.98	.51	.68	.43	.38	.36	.35	.73
.45	1.50	.68	.60	.45	.41	.65	.92	.46	.66	.39	.35	.34	.33	.68
.55	1.41	.62	.57	.42	.37	.61	.84	.40	.64	.35	.32	.32	.31	.61
.65	1.32	.56	.54	.38	.32	.57	.74	.34	.62	.31	.28	.30	.29	.53
.75	1.21	.50	.50	.32	.27	.52	.62	.28	.59	.26	.23	.28	.26	.45
.85	1.10	.43	.46	.26	.21	.47	.50	.22	.56	.20	.17	.25	.23	.37
.95	.94	.36	.40	.18	.14	.40	.36	.14	.52	.13	.10	.19	.19	.25
Mean	1.41	.61	.564	.40	.36	.59	.81	.41	.64	.35	.31	.31	.31	.59
.60	1.37	.59	.56	.40	.35	.59	.80	.37	.63	.33	.30	.31	.30	.57

Character of river bed: From station 0 to 55 the bed is a rock ledge, and from station 55 to the left bank it is small gravel, none over 0.2 foot in diameter.

TABLE IX.—*Velocities in vertical sections on Fishkill Creek at Glenham.*

Date	July 24.	Aug. 15.	Aug. 15.	Aug. 30.	Aug. 30.	Aug. 30.	Sept. 6.	Sept. 6.	Sept. 27.	Oct. 5.	Oct. 25.	Nov. 11.	Nov. 20.
Point of measurement	51.	50.	55.	45.	50.	55.	60.	65.	75.	55.	85.	55.	50.
Gage height, feet	3.60.	3.85.	3.85.	4.60.	4.60.	4.60.	4.15.	4.15.	3.86.	3.98.	4.05.	3.85.	3.95.
Depth	3.6.	4.0.	3.4.	4.4.	4.4.	4.2.	3.8.	3.2.	2.9.	3.5.	2.8.	3.4.	4.0.
Bed of creek	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.	Gravel.
Wind	Gentle.	Strong.	Strong.	Gentle.	Gentle.	Gentle.	None.	None.	Gentle.	Gentle.	Fresh.	None.	Gentle.
Direction	Up-stream.	Down-stream.	Down-stream.	Down-stream.	Down-stream.	Down-stream.	.....	.....	Down-stream.	Down-stream.	Up-stream.	.....	Up-stream.

Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
0.2	0.54	0.2	0.75	0.2	0.73	0.2	1.70	0.2	1.42	0.2	1.47	0.2	1.05	0.2	1.21	0.3	0.06	0.4	0.93	0.3	1.05	0.4	0.62	0.5	0.69
.7	.54	.7	.75	.7	.75	.7	1.89	.7	1.77	.7	1.75	.7	1.17	.7	1.24	.8	.64	.9	.90	.8	1.02	.9	.60	1.0	.64
1.2	.45	1.2	.73	1.2	.71	1.2	1.87	1.2	1.75	1.2	1.70	1.2	1.17	1.2	1.17	1.3	.61	1.4	.87	1.3	.97	1.9	.56	1.7	.65
1.7	.38	1.7	.68	1.7	.68	1.7	1.96	1.7	1.72	1.7	1.67	1.7	1.14	1.7	1.14	1.7	.56	1.9	.87	1.7	.97	2.0	.57	2.4	.65
2.2	.38	2.2	.66	2.2	.63	2.2	1.79	2.2	1.67	2.2	1.61	2.2	1.03	2.2	.98	1.8	.57	2.1	.85	2.3	.67	2.9	.42	2.9	.59
2.7	.29	2.4	.66	2.7	.50	2.7	1.75	2.7	1.61	2.7	1.54	2.7	.94	2.9	.50	2.3	.46	2.5	.85	.....	.....	.....	.....	3.5	.54
3.1	.27	2.7	.54	.....	.....	3.2	1.61	3.2	1.52	3.2	1.54	3.3	.73	.....	.....	.....	.....	3.0	.70	.....	.....	.....	.....	.....	.....
.....	.....	3.2	.45	.....	.....	3.7	1.49	3.7	1.30	3.7	1.38	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	3.9	1.29	3.9	1.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE X.—*Velocities at regular intervals in vertical sections on Fishkill Creek at Glenham, deduced from data in Table IX.*

[Velocities in feet per second.]

Depths in parts of total.	July 24.	Aug. 15.	Aug. 15.	Aug. 30.	Aug. 30.	Aug. 30.	Sept. 6.	Sept. 6.	Sept. 27.	Oct. 5.	Oct. 25.	Nov. 11.	Nov. 20.
0.05	0.54	0.75	0.74	1.77	1.64	1.63	1.06	1.21	0.67	0.95	1.05	0.62	0.67
.15	.54	.75	.75	1.87	1.74	1.71	1.15	1.22	.66	.93	1.05	.62	.68
.25	.51	.74	.74	1.92	1.75	1.71	1.18	1.21	.65	.90	1.04	.61	.67
.35	.47	.72	.72	1.91	1.73	1.68	1.16	1.19	.63	.88	1.02	.60	.66
.45	.43	.68	.70	1.86	1.69	1.64	1.12	1.16	.61	.87	1.00	.59	.65
.55	.39	.63	.67	1.78	1.64	1.60	1.06	1.11	.58	.86	.97	.57	.64
.65	.34	.56	.63	1.69	1.58	1.56	.98	1.02	.55	.85	.89	.54	.62
.75	.29	.48	.59	1.59	1.50	1.51	.88	.88	.52	.81	.80	.50	.58
.85	.23	.40	.55	1.45	1.38	1.44	.76	.70	.45	.75	.67	.44	.54
.95	.16	.30	.51	1.26	1.15	1.32	.62	.50	.35	.65	.53	.35	.49
Mean	.39	.60	.66	1.71	1.58	1.58	1.00	1.02	.57	.85	.90	.54	.62
.60	.37	.60	.65	1.74	1.61	1.58	1.02	1.07	.57	.86	.93	.56	.63

Character of bed of creek: Bowlders from 0.2 foot to 0.6 foot in diameter.

TABLE XI.—*Velocities in vertical sections on Tenmile River at Dover Plains.*

Date	Oct. 15.		Oct. 26.		Oct. 26.		Nov. 11.		Nov. 22.	
Point of measurement	55.		25.		55.		25.		25.	
Gage height	7.19.		5.01.		5.01.		4.75.		4.76.	
Depth	6.8.		4.6.		4.8		4.4.		4.2.	
Bed of creek	Sand.		Sand.		Sand.		Sand.		Sand.	
Wind	Fresh.		None.		None.		None.		Gentle.	
Direction	Downstream.								Downstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.5	2.43	0.3	1.10	0.5	1.00	0.4	0.90	0.3	0.84
	1.5	2.38	.8	1.07	1.5	.95	.9	.87	.8	.84
	2.5	2.31	1.3	1.00	2.5	.93	1.4	.77	1.5	.73
	3.5	2.19	1.8	.92	2.9	.92	2.0	.70	2.0	.75
	4.1	2.17	2.3	.90	3.5	.90	2.6	.67	2.5	.67
	4.4	2.09	2.8	.82	4.3	.77	3.0	.61	3.0	.56
	5.3	2.00	3.3	.75			3.5	.55	3.5	.55
	6.3	1.84	4.1	.62			3.9	.50	3.7	.49

TABLE XII.—*Velocities at regular intervals in vertical sections on Tenmile River at Dover Plains, deduced from data in Table XI.*

[Velocities in feet per second.]

Depths in parts of total.	Oct. 15.	Oct. 26.	Oct. 26.	Nov. 11.	Nov. 22.
0.05	2.44	1.08	0.99	0.89	0.84
.15	2.42	1.06	.99	.86	.84
.25	2.36	1.03	.98	.83	.82
.35	2.30	.98	.97	.79	.78
.45	2.23	.93	.95	.75	.74
.55	2.16	.87	.93	.70	.70
.65	2.09	.81	.91	.64	.65
.75	2.02	.73	.88	.58	.59
.85	1.95	.65	.82	.52	.51
.95	1.83	.46	.68	.44	.43
Mean	2.18	.86	.91	.70	.69
.60	2.13	.84	.92	.67	.68

TABLE XIII.—*Velocities in vertical sections on Housatonic River at Gaylordsville.*

Date	Aug. 8.		Oct. 29.		Nov. 13.		Nov. 23.	
Point of measurement	60.		60.		60.		60.	
Gage height	3.50.		4.05.		4.82.		4.11.	
Depth	3.8.		4.8.		6.2.		4.8.	
Bed of creek	Gravel.		Gravel.		Gravel.		Gravel.	
Wind	None.		None.		Very strong.		Gentle.	
Direction					Downstream.		Upstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.20	2.19	0.5	2.98	0.5	3.84	0.5	3.08
	.30	2.23	1.5	2.90	1.5	3.93	1.5	2.92
	.8	2.25	2.5	2.85	2.5	3.84	2.5	2.81
	1.3	2.14	2.9	2.68	3.5	3.50	2.9	2.61
	1.8	2.07	3.5	2.39	3.7	3.44	3.5	2.38
	2.3	2.05	4.3	1.92	4.5	3.23	4.3	1.90
	2.8	1.72			5.6	2.50		
	3.3	1.35						

TABLE XIV.—*Velocities at regular intervals in vertical sections on Housatonic River at Gaylordsville, deduced from data in Table XIII.*

[Velocities in feet per second.]

Depths in parts of total.	Aug. 8.	Oct. 29.	Nov. 13.	Nov. 23.
0.05	2.21	3.00	3.89	3.02
.15	2.23	2.97	3.90	3.01
.25	2.21	2.94	3.91	3.00
.35	2.17	2.90	3.89	2.94
.45	2.10	2.85	3.79	2.85
.55	2.02	2.77	3.60	2.72
.65	1.85	2.57	3.38	2.52
.75	1.66	2.35	3.11	2.34
.85	1.45	2.10	2.79	2.10
.95	1.20	1.75	2.04	1.80
Mean	1.91	2.62	3.43	2.63
.60	1.94	2.67	3.49	2.62

For the purpose of comparison a mean curve for each of the streams has been determined by taking the mean of all the velocities shown in each of Tables II, IV, VI, VIII, X, XII, and XIV. To facilitate comparison, the data for these mean curves have been expressed in percentages of the mean velocity in a vertical section, and are shown in Table XV, the total number of curves being 78. By this arrangement a figure in the column greater than 100 shows a velocity greater than the mean in the vertical section being considered, and a velocity less than 100 shows a velocity less than the mean. The mean curves have been plotted in fig. 2. It will be seen from these curves that the general character of the vertical velocity curves is much the same in each

case, showing fairly conclusively that we may prophesy as to the general character of the vertical velocity curve in natural streams with steep banks and from smooth to moderately rough bottoms, and depths of from 3 to 8 feet. It will be noted that the ratio of the mean velocity to the surface velocity varies from 92 per cent on the Fishkill to 82 per cent on the Catskill, and that the maximum velocity of these streams varies from 13 to 25 per cent greater than the mean, and that at no point do all of the curves fall so closely together as at six-tenths depth. At that point the greatest variation from the mean is 2½ per cent. This shows that the measurements made at six-tenths depth were subject to less variation than those made at any other point, and that in general, on streams of the character here represented, a measurement made at that point would represent approximately the mean velocity in the section. It will be noted that none of the curves cross the line of mean velocity at a greater depth than 0.63, nor at a less depth than 0.56, showing that the point of mean velocity on these streams lies between these two depths.

TABLE XV.—*Averages of velocity curves expressed in terms of mean velocity in a vertical section (represented as 100).*

Stream	Esopus.			Rondout.	Wallkill.	Catskill.	Fishkill.	Tenmile.	Housatonic.	Average of all the streams.
No. of velocity curves.	12.	8.	20.	13.	9.	14.	13.	5.	4.	78.
Bed of stream..	Small gravel.	Bowlders.	Average.	Bowlders.	Silt.	Small gravel and rock ledge.	Large gravel.	Sand.	Gravel.	Various.
Mean depth	6.5.	4.7.	5.8.	6.	7.3.	3.2.	3.7.	5.	4.9.	5.07.
Depth below surface in parts of total:										
0.05	118.6	115.9	117.3	117.9	119.7	124.7	110.7	116.8	114.4	117.0
.15	120.8	116.6	118.8	119.6	118.4	124.8	113.7	115.6	114.3	117.9
.25	118.9	115.5	117.3	118.5	115.4	121.8	113.4	112.7	113.9	116.3
.35	115.0	112.7	113.9	115.9	111.6	116.5	111.3	109.0	112.4	113.2
.45	109.3	109.4	109.3	111.7	107.4	109.7	108.2	104.9	109.5	109.0
.55	102.3	104.8	103.5	105.9	102.5	101.5	104.0	100.4	105.0	103.6
.65	94.4	98.6	96.4	97.2	96.3	92.5	98.3	95.5	97.4	96.5
.75	85.5	89.7	87.5	86.3	89.0	81.9	91.0	89.9	89.3	87.9
.85	74.9	77.8	76.3	72.8	78.6	70.7	81.2	83.3	79.7	77.2
.95	60.3	59.0	59.7	54.2	61.1	55.9	68.2	71.9	64.1	61.4
Mean	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
.60	98.9	101.7	100.2	101.8	99.6	97.2	101.4	98.1	101.2	100.26

In Table XV, under the heading "Average of all the streams," the mean velocity of each depth given in the table is shown, and the curve representing this mean vertical velocity curve is platted in fig. 3 as a solid line. This curve represents the mean of 78 vertical velocity curves, the mean *of the vertical* velocity curves platted in fig. 2.

It will be noted in this curve that the relation between the mean velocity and the surface velocity is 87; that the maximum velocity is 18 per cent greater than the mean, and that the point of mean velocity is almost exactly at six-tenths depth, the variation, as shown in the last column of Table XV, being about one-fourth of 1 per cent. This shows clearly that a measurement made at six-tenths of the depth of a stream having the general characteristics of those considered will in general represent closely the mean velocity in that section.

To show the relation between the velocity at mid depth and the mean velocity in a vertical section Table XVI has been compiled from Table XV. From this table it will be seen that, upon streams like these being considered, if the mid depth is known, the mean velocity in the vertical section may be found by applying a coefficient of 0.94.

TABLE XVI.—*Relation between velocity at mid depth to mean velocity in a vertical section.*

Stream.	Velocity at mid depth expressed in percentage of the mean.	Coefficient to be applied to velocity at mid depth to obtain mean velocity.
Esopus	106.4	0.94
Rondout	108.8	.92
Wallkill	104.9	.95
Catskill	105.6	.94
Fishkill	106.1	.94
Tennile	102.6	.97
Housatonic	107.2	.93
Average	106.3	.94

Humphreys's and Abbott's observations on the Mississippi River gave a coefficient of 0.98, while Ellis, on the Connecticut, found 0.94, and Wheeler and Lynch, on the Merrimac flume, found 0.95. It will be seen that there is a variation of 5 per cent on the streams being considered in this paper, and that the results of Humphreys and Abbott on the Mississippi and Ellis on the Connecticut vary from each other by 4 per cent, although the rivers are both large and have somewhat the same characteristics. In view of these facts, it seems that it is somewhat better to measure the velocity at the point of mean velocity than to measure the velocity at mean depth and apply a coefficient.

It is very evident that the character of the bed will affect to some extent the form of the vertical velocity curve. A rough bed would be expected to retard the velocity near the bottom of the stream. None of the streams under investigation may be considered to have *extremely rough beds, but* by comparison the beds of Rondout Creek

and Housatonic River may be said to be rough, while those of the Wallkill River and Tenmile Creek are smooth at the point of measurement. Part of the bed of the Esopus is rough and part smooth. In order to determine the effect of the variation in the beds on the flow, the results in Table XV have been classified in Table XVII into streams with rough and smooth bottoms, the Rondout, Housatonic, and part of the curves on the Esopus being in the first column, and the Wallkill, Tenmile, and remaining observations on the Esopus in the second. The results shown in these two columns have been plotted in fig. 3.

It will be seen that the rough bed causes a drag at the lower end of the vertical velocity curve, due largely to eddies formed at the bottom of the stream. This retardation of the water near the bed of the stream causes the point of mean velocity in the vertical section to rise, and a measurement of velocity made at 0.60 depth will therefore be too small. With a smooth bed a measurement made at 0.60 depth will, in general, be too large, the filament of mean velocity being nearer the surface. In other words, in making a measurement of mean velocity in a vertical section the meter should, in general, be suspended above 0.60 depth in streams of rough bed and below 0.60 depth in streams of smooth bed. In the rivers here considered the variation of roughness of beds is so small in the different streams that the error in assuming the velocity at 0.60 depth to be the mean velocity in the vertical section would not be great, but in streams of very rough beds the variation would be more marked.

TABLE XVII.—*Relation between velocities in vertical sections with smooth and rough bottoms.*

Depth below surface—in parts of total.	Smooth bottom: Esopus, Wallkill, Tenmile.	Rough bottom: Rondout, Housatonic.
	Velocity in percentage of the mean.	*Velocity in percentage of the mean.*
0.05	118.7	116.2
.15	118.8	117.0
.25	116.2	116.0
.35	112.4	113.8
.45	107.6	110.3
.55	102.0	105.3
.65	95.4	97.7
.75	87.8	88.3
.85	78.1	76.5
.95	63.0	58.9
Mean	100.0	100.0
.60	99.0	101.6

FLOW OF RIVERS UNDER ICE, SMOOTH AND UNBROKEN COVER.

It is frequently desirable to measure the flow of rivers and canals when they are covered with a coating of ice. It is quite clear that the same relations in various parts of the channel do not hold good when the channel is covered with ice as when the surface is open. The friction between the water and the ice retards the surface velocity, and it is possible that in a few cases the river may flow under a head if the ice cake is heavy and held firmly in position. In making measurements of the flow of a river when frozen over, floats can not be used, and in general a current meter is the most serviceable instrument.

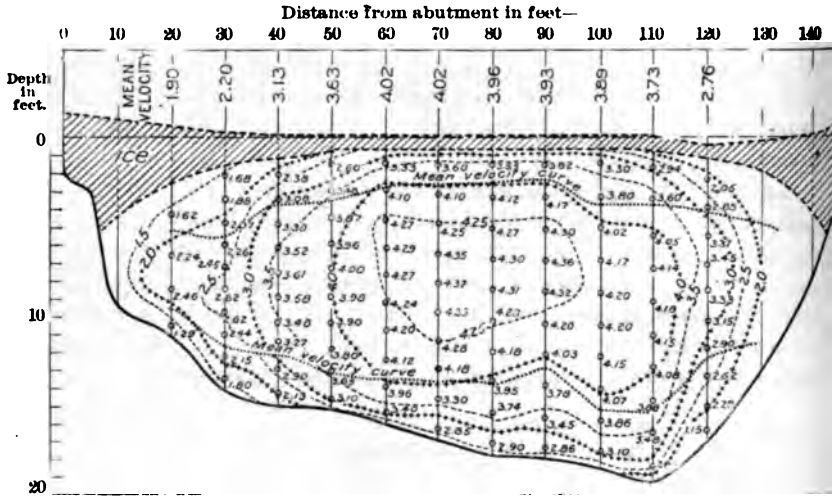


FIG. 4.—Cross section of Wallkill River at New Paltz, showing ice cover and curves of equal velocity in river channel. (Note.—Measurements taken January 23, 1902; 117 measurements of velocity being made with the current meter; mean velocity, 3.23 feet per second; discharge, 6,063 second-feet. The dotted line shows the position of mean velocity in the vertical section.)

During the winter of 1901–2 observations to determine the change of velocity in a vertical plane below the ice were made on Wallkill River, and Esopus, Rondout, and Catskill creeks, and the data collected are presented in the following tables.[a] The observations were made by cutting holes through the ice large enough to admit a current meter. The thickness of the ice in each case is given in the table and the fact that the water rose in most cases to a point about flush with the surface of the ice shows that there was some pressure upon the flowing stream. It may be of interest in passing to note the distribution of the velocity in the cross section, as shown in fig. 4, the result of the gagings made on the Wallkill River at the New Paltz gaging station, January 23, 1902. The total area of the water section was 1,880 square feet, the mean velocity 3.23, and the discharge 6,063 second-feet. One hundred and seventeen measurements were

[a] *These observations were made incidental to the discharge measurements of the streams.*

made with the current meter, and the points are platted in the figure, the velocity in feet per second being noted beside each point. The mean velocity in feet per second in a vertical section is shown by the figures across the top of the section. A dotted line showing the position of the mean velocity in the vertical sections has been drawn on the cross section. It will be seen that the maximum velocity occurs near the center of the channel, and at about mid depth, and that the effect of the ice covering is to form a covered flume, the curves of equal velocity being much the same as have been plotted occasionally for such flumes. The water just below the ice is so retarded that there are two points of mean velocity, as shown in figs. 4 and 5.

In the following tables are given the results of measurements made in vertical sections upon the above-mentioned rivers. These measurements were made with a single meter, the velocities being taken at intervals of from 1 to 2 feet, these distances being shown in each case in the table. Tables XVIII, XX, XXII, XXIV, and XXVI show the velocities as determined by actual measurements. At the head of the table are given the date, distance from initial point of sounding, gage height at the time of measurement, total depth of the river (including ice), the thickness of ice, and the depth of water under the ice. In every case the depth, as given in the body of the table, refers to the depth of water under the ice, the lower surface of the ice being considered as zero, and the distances being measured in feet and tenths. Where not otherwise stated, the ice was smooth on the lower side. Some curves were made with ice broken and tilted, but the results were quite different from those obtained with smooth ice, and the results have been given in separate tables (XXIX to XXXIII). The retarding influence of the rough ice was decidedly greater than that of the smooth ice and is so variable that no law can be formulated.

Tables XIX, XXI, XXIII, XXV, and XXVII are derived from the preceding tables by platting the vertical velocity curves, as shown by the original data, and taking from this curve the velocities at regular intervals, one-tenth of the depth apart. The sum of these velocities divided by 10 will give the mean in the section.

In Table XIX, and the others of a similar character, a column has been added, headed "Per cent of mean." The figures of this column are obtained by dividing the corresponding figures in the adjacent column by the mean velocity, which reduces the data for each velocity curve to a similar curve whose mean is 100, and as the depths are then expressed as percentages of total depth, and the velocities as percentages of the mean velocity, the comparison between the curves is facilitated. In all cases for which the data are included within these tables the ice on the surface was smooth both on its upper and lower faces. The few velocity curves taken at times when the ice was broken and tilted are shown in separate tables.

TABLE XVIII.—*Velocities in vertical sections under ice on Wallkill River.*[a]

1901-1902.

Date	Dec. 11.		Dec. 11.		Dec. 11.		Dec. 11.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.	
Point of measurement	85.		75.		53.		40.		50.		80.		90.		100.		40.		50.		60.		70.		80.	
Gage height	11.50.		11.50.		11.50.		11.50.		7.24.		7.24.		7.24.		7.24.		17.33.		17.33.		17.33.		17.33.		17.33.	
Total depth	12.3.		12.2.		9.9.		9.4.		4.6.		6.8.		7.6.		8.8.		15.4.		16.0.		14.8.		16.8.		17.7.	
Thickness of ice	0.7.		0.7.		0.7.		0.4.		1.2.		1.0.		1.0.		1.0.		1.4.		1.0.		0.8.		0.8.		0.7.	
Depth of water	11.6.		11.5.		9.2.		9.0.		3.4.		5.8.		6.6.		7.8.		14.0.		15.0.		14.0.		16.0.		17.0.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.8	2.52	0.8	2.43	0.8	2.14	0.3	2.24	0.3	0.80	0.3	0.77	0.3	0.62	0.3	0.87	0.5	2.21	0.5	2.61	0.4	3.23	0.4	3.15	0.3	1.45
	2.8	3.03	2.8	3.13	2.8	2.68	1.3	2.64	1.3	.95	1.3	1.12	1.3	1.22	1.3	1.15	1.5	3.13	1.4	3.50	1.3	3.91	1.2	3.72	1.0	3.37
	4.8	3.11	4.8	3.18	4.8	2.68	3.3	2.90	2.3	.85	2.3	1.22	2.3	1.25	2.3	1.25	3.5	3.37	2.2	3.84	2.3	4.19	2.8	4.12	2.6	4.12
	6.8	2.78	6.8	2.73	6.8	2.71	5.2	2.76	2.8	.67	3.3	1.12	3.3	1.20	3.3	1.27	5.5	3.55	3.8	3.93	4.2	4.30	4.4	4.21	4.2	4.26
	8.8	2.38	8.8	2.43	8.7	2.12	7.0	2.31	.....	.....	4.3	1.00	4.3	1.05	4.3	1.22	7.5	3.60	5.7	3.93	6.0	4.26	5.8	4.32	5.8	4.28
	10.8	1.62	11.0	1.65	.....	.....	8.5	1.62	.....	.....	5.3	.77	5.3	.87	5.3	1.15	9.5	3.41	7.6	3.95	7.9	4.23	7.4	4.37	7.4	4.32
													6.1	.70	6.3	.95	11.5	3.03	8.5	3.97	9.8	4.19	9.0	4.35	9.0	4.30
															7.3	.70	13.5	1.98	9.3	3.97	11.7	4.12	10.5	4.26	10.5	4.23
																			10.2	3.97	12.6	3.79	12.0	4.21	12.0	4.07
																			11.0	3.95	13.5	3.18	13.6	4.02	13.5	3.88
																			12.0	3.74	.....	.....	14.2	3.84	15.0	3.60
																			12.8	3.48	.....	.....	14.9	3.03	15.8	3.06
																			13.7	3.01	.....	.....	15.5	2.36	16.5	2.43
																			14.5	2.24	.....	.....	.....	.....	.....	.....

Date	Jan. 23.		Jan. 23.		Jan. 23.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Feb. 10.		Feb. 10.		Feb. 24.		Feb. 24.		Feb. 24.	
Point of measurement	90.		100.		110.		40.		70.		80.		90.		100.		80.		90.		90.		80.		40.	
Gage height	17.33.		17.33.		17.33.		9.07.		9.07.		9.07.		9.07.		9.07.		7.78.		7.78.		7.33.		7.31.		7.33.	
Total depth	17.7.		18.8.		19.8.		6.8.		8.8.		8.8.		10.0.		11.5.		7.5.		8.5.		8.0.		7.3.		5.9.	
Thickness of ice	0.7.		0.8.		0.8.		1.0.		1.0.		1.0.		1.0.		1.2.		1.0.		1.0.		2.0.		2.0.		2.4.	
Depth of water	17.0.		18.9.		19.0.		5.8.		7.8.		7.8.		9.0.		10.3.		6.5.		7.5.		6.0.		5.3.		3.5.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.3	3.23	0.3	2.36	0.7	2.73	0.3	1.32	0.4	1.98	0.3	1.65	0.3	1.70	0.3	1.77	0.3	1.10	0.3	1.15	0.2	0.73	0.3	0.75	0.25	0.42
	1.1	3.88	1.2	3.58	1.7	3.03	1.3	1.65	1.3	2.21	1.3	2.31	1.5	2.33	0.8	2.03	1.0	1.45	1.0	1.52	0.5	.82	.8	.85	0.5	.55
	2.6	4.21	2.2	3.72	3.4	3.55	2.3	1.72	2.3	2.43	2.3	2.45	3.5	2.45	2.8	2.38	3.0	1.65	2.0	1.72	1.5	1.05	1.8	1.00	1.0	.62
	4.2	4.26	4.0	3.93	5.1	4.02	4.3	1.52	4.3	2.29	4.3	2.31	5.5	2.24	4.8	2.47	5.0	1.34	4.0	1.50	2.5	1.02	2.8	.97	1.5	.62
	5.8	4.30	5.7	4.12	6.8	4.12	5.3	1.20	6.3	1.79	6.3	2.00	7.5	1.72	6.8	2.43	6.0	1.10	6.0	1.22	3.5	.92	3.8	.87	2.0	.59
	7.4	4.35	7.4	4.17	8.5	4.17	.....	.....	7.3	1.37	7.3	1.62	8.5	1.37	8.8	2.07	.....	.....	7.0	1.07	4.5	.74	4.8	.62	2.5	.50
	9.0	4.26	9.1	4.21	10.2	4.14	.....	.....	.....	.....	.....	.....	.....	.....	9.8	1.65	.....	.....	.....	.....	5.5	.65	.....	.....	3.0	.42
	10.5	4.09	10.8	4.17	11.9	4.09	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	12.0	3.95	12.5	4.09	13.6	4.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	13.5	3.65	14.2	4.05	15.3	3.88	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	14.3	3.53	15.9	3.91	17.0	3.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	16.0	3.01	16.7	3.70	17.8	2.94	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	16.5	2.52	17.5	2.43	18.5	2.52	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[a] Bed of river, silt.

TABLE XIX.—*Velocities at regular intervals in vertical sections on Wallkill River, under ice, deduced from data in Table XVIII.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Dec. 11.		Dec. 11.		Dec. 11.		Dec. 11.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	2.47	95	2.35	89	2.02	81	2.22	89	0.75	92	0.77	76	0.70	69	0.90	84	2.38	76	2.60	72	3.33	83	3.60	89	3.55	90		
.15	2.81	108	2.81	107	2.32	93	2.53	101	.87	107	1.00	99	1.10	108	1.12	104	3.08	98	3.48	96	4.10	102	4.10	102	4.12	104		
.25	3.06	117	3.15	119	2.57	103	2.74	110	.93	114	1.14	113	1.23	121	1.22	113	3.38	107	3.87	107	4.27	106	4.25	106	4.27	107		
.35	3.13	120	3.22	122	2.70	109	2.88	115	.95	117	1.20	118	1.25	123	1.27	117	3.52	113	3.96	109	4.29	107	4.35	108	4.30	109		
.45	3.07	118	3.12	118	2.74	110	2.89	116	.94	115	1.18	117	1.23	121	1.27	118	3.61	115	4.00	110	4.27	106	4.37	109	4.31	109		
.55	2.88	111	2.94	111	2.75	111	2.82	113	.92	113	1.15	114	1.17	115	1.23	114	3.58	114	3.98	109	4.24	105	4.35	108	4.28	108		
.65	2.67	102	2.69	102	2.72	110	2.66	107	.87	107	1.08	107	1.06	105	1.16	108	3.48	111	3.90	107	4.20	104	4.28	106	4.18	105		
.75	2.41	92	2.42	92	2.60	105	2.42	97	.78	96	.99	98	.94	93	1.05	98	3.27	104	3.80	105	4.12	103	4.18	104	3.99	101		
.85	2.06	79	2.06	78	2.38	96	2.15	86	.65	80	.88	87	.82	81	88	82	2.90	93	3.65	100	3.96	99	3.90	97	3.74	94		
.95	1.50	58	1.64	62	2.05	82	1.63	66	.48	59	.72	71	.65	64	67	62	2.13	69	3.10	85	3.40	85	2.85	71	2.60	73		
Mean	2.61	100	2.64	100	2.48	100	2.49	100	0.81	100	1.01	100	1.01	100	1.08	100	3.13	100	3.63	100	4.02	100	4.02	100	3.96	100		

Depth in parts of total.	Jan. 23.		Jan. 23.		Jan. 27.		Jan. 31.		Jan. 31.		Jan. 31.		Feb. 10.		Feb. 10.		Feb. 24.		Feb. 24.		Feb. 24.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	3.82	97	3.20	85	2.34	79	1.30	85	1.94	93	1.78	83	1.81	87	1.91	85	1.15	80	1.18	83	0.78	82	0.68	80	0.30	71
.15	4.17	108	3.80	98	3.60	86	1.53	100	2.24	108	2.26	106	2.29	109	2.21	99	1.44	101	1.56	110	.90	108	.87	103	.55	108
.25	4.10	106	4.02	103	4.05	100	1.68	110	2.40	115	2.42	113	2.44	117	2.30	105	1.58	111	1.70	120	1.04	122	.96	114	.61	120
.35	4.36	111	4.17	107	4.14	111	1.73	113	2.44	117	2.44	114	2.46	118	2.45	110	1.65	115	1.72	121	1.08	121	1.00	118	.62	121
.45	4.32	110	4.20	108	4.18	112	1.72	113	2.40	115	2.40	112	2.42	116	2.48	111	1.64	115	1.68	118	.99	110	.90	117	.61	119
.55	4.20	107	4.20	108	4.15	111	1.68	110	2.30	110	2.32	109	2.32	111	2.47	110	1.60	112	1.58	111	.93	109	.90	114	.58	114
.65	4.01	103	4.15	107	4.08	109	1.62	107	2.14	103	2.22	104	2.17	104	2.44	109	1.52	107	1.45	102	.85	100	.90	107	.55	108
.75	3.78	96	4.07	105	3.88	104	1.52	100	1.96	94	2.10	98	1.96	94	2.33	104	1.40	99	1.30	92	.76	90	.83	98	.49	96
.85	3.45	88	3.86	99	3.48	93	1.34	88	1.80	87	1.90	89	1.69	81	2.08	93	1.23	87	1.12	79	.66	78	.71	84	.42	82
.95	2.85	73	3.10	80	2.84	76	1.12	74	1.33	64	1.53	72	1.32	63	1.64	74	1.04	73	.90	64	.56	66	.55	65	.31	61
Mean	3.93	100	3.89	100	3.73	100	1.52	100	2.08	100	2.14	100	2.09	100	2.24	100	1.42	100	1.42	100	0.85	100	0.84	100	0.51	100

a The lower surface of the ice is zero depth.

TABLE XX.—*Velocities in vertical sections under ice on Esopus Creek.*[a]

Date	Jan. 9		Feb. 20		Feb. 28		Dec. 4		Dec. 4		Jan. 9		Jan. 9		Feb. 20	
Point of measurement	80.		80.		40.		90.		100.		90.		100.		90.	
Gage heights	6.55.		5.38.		9.14.		5.28.		5.28.		6.55.		6.55.		5.38.	
Total depth	6.8.		5.8.		6.3.		6.85.		5.05.		8.1.		6.1.		6.6.	
Thickness of ice	0.2.		0.1.		0.3.		0.05.		0.05.		0.1.		0.1.		0.2.	
Depth of water	6.6.		5.7.		6.0.		6.8.		5.0.		8.0.		6.0.		6.4.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.3	1.25	0.3	0.67	0.5	2.56	0.5	0.72	0.5	0.97	0.3	1.10	0.3	0.97	0.2	0.75
	1.3	1.50	1.2	.97	1.5	3.01	1.5	.85	1.5	1.07	1.3	1.35	1.3	1.27	0.9	.97
	2.3	1.52	2.2	.91	2.5	2.99	2.5	1.05	2.5	1.07	2.3	1.40	2.3	1.32	1.9	1.02
	3.3	1.50	3.2	.90	3.5	2.90	3.5	1.10	3.0	1.07	3.3	1.37	3.3	1.30	2.9	.95
	4.3	1.42	4.2	.87	4.5	2.29	4.1	1.09	3.5	1.07	4.3	1.32	4.3	1.25	3.9	.85
	5.3	1.32	5.2	.66	5.5	1.65	4.5	1.00	4.5	.62	5.3	1.17	5.5	1.02	4.9	.72
	6.1	1.10					5.6	.82			6.3	.90			5.9	.57
							6.3	.50			7.5	.60				

[a] Bed of river 40 to 80 is bowlders, 90 to 100 silt.

TABLE XXI.—*Velocities at regular intervals in vertical sections on Esopus Creek under ice, deduced from data in Table XX.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Jan. 9.		Feb. 20.		Feb. 28.		Dec. 4.		Dec. 4.		Jan. 9.		Jan. 9.		Feb. 20.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	1.26	91	0.67	81	2.40	93	0.67	75	0.98	96	1.14	99	0.97	81	0.73	88
.15	1.45	105	.85	102	2.75	107	.82	93	1.00	105	1.34	116	1.18	98	.98	112
.25	1.52	109	.94	113	3.00	116	.94	106	1.05	111	1.40	121	1.30	108	.99	119
.35	1.53	110	.95	114	3.08	119	1.03	116	1.07	113	1.40	122	1.33	111	1.01	122
.45	1.51	109	.93	112	3.02	117	1.09	122	1.08	114	1.36	118	1.32	110	.96	115
.55	1.49	107	.91	110	2.88	112	1.10	122	1.08	114	1.30	113	1.30	108	.90	108
.65	1.44	105	.88	106	2.70	105	1.05	118	1.05	111	1.19	103	1.27	106	.83	100
.75	1.37	99	.83	100	2.45	95	.92	102	.96	101	1.03	89	1.23	102	.75	91
.85	1.26	91	.75	91	2.07	80	.77	86	.78	82	.83	72	1.14	95	.66	80
.95	1.02	74	.59	71	1.45	56	.53	60	.50	51	.54	47	.97	81	.54	65
Mean	1.385	100	.83	100	2.58	100	.89	100	.95	100	1.15	100	1.20	100	.83	100

[a] The lower surface of the ice is zero depth.

TABLE XXII.—*Velocities in vertical sections under ice on Rondout Creek.*[a]

Date	Dec. 6.		Dec. 6.		Jan. 14.		Jan. 14.		Feb. 26.		Feb. 26.		Feb. 26.		Feb. 26.	
Point of measurement	80.		90.		80.		90.		92.		92.		80.		40.	
Gage height	6.80.		6.80.		7.00.		7.00.		8.13.		8.43.		8.13.		8.13.	
Total depth	6.2.		6.6.		6.5.		7.0.		7.7.		8.0.		7.9.		6.4.	
Thickness of ice	0.1.		0.2.		0.2.		0.2.		1.5.		1.4.		1.5.		1.0.	
Depth of water	6.1.		6.4.		6.3.		6.8.		6.2.		6.6.		6.4.		5.4.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
	0.4	0.62	0.3	0.55	0.8	1.05	0.8	1.07	0.3	0.92	0.3	1.70	0.3	1.40	0.4	1.30
	1.4	.73	1.3	.70	1.8	1.32	2.3	1.27	1.5	1.47	1.1	1.91	0.9	1.62	0.9	1.55
	2.4	.77	2.3	.65	2.8	1.47	3.3	1.27	2.5	1.59	2.1	2.00	1.9	1.67	1.9	1.67
	3.4	.71	3.3	.61	3.8	1.40	4.3	1.15	3.5	1.52	3.1	1.98	2.9	1.67	2.9	1.65
	4.5	.62	4.4	.55	4.8	1.35	5.3	1.10	4.6	1.25	4.1	1.73	3.9	1.60	3.9	1.57
	5.6	.51	5.9	.45	5.8	1.07	6.3	1.07	5.7	.82	5.1	1.32	4.9	1.42	4.9	1.32
											6.1	.85	5.9	1.15		

[a] Bed of creek is rock, with some bowlders from 0 to 40 and broken rock from 0.5 to 1 foot in diameter the remainder of width.

TABLE XXIII.—*Velocities at regular intervals in vertical sections on Rondout Creek under ice, deduced from data in Table XXII.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Dec. 6.		Dec. 6.		Jan. 14.		Jan. 14.		Feb. 26.		Feb. 26.		Feb. 26.		Feb. 26.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	0.61	93	0.55	95	0.85	69	0.96	84	0.95	74	1.60	98	1.40	93	1.23	81
.15	.68	104	.65	112	1.09	88	1.12	98	1.30	101	1.90	116	1.62	107	1.50	99
.25	.75	114	.68	117	1.27	102	1.23	108	1.52	118	1.98	121	1.67	110	1.62	107
.35	.76	116	.67	116	1.40	113	1.27	112	1.58	122	2.02	123	1.68	111	1.67	111
.45	.75	114	.64	111	1.47	119	1.27	112	1.57	121	2.02	123	1.67	111	1.67	111
.55	.72	110	.61	106	1.46	118	1.25	110	1.53	118	1.87	114	1.64	109	1.65	109
.65	.67	102	.57	99	1.41	113	1.20	105	1.44	112	1.67	102	1.57	104	1.60	106
.75	.62	94	.53	91	1.31	106	1.12	99	1.27	99	1.42	86	1.46	97	1.54	102
.85	.55	84	.48	83	1.18	95	1.04	91	1.03	80	1.13	69	1.32	87	1.42	94
.95	.45	69	.40	70	.96	77	.92	81	.71	55	.79	48	1.07	71	1.20	80
Mean	.66	100	.58	100	1.24	100	1.14	100	1.29	100	1.64	100	1.51	100	1.51	100

[a] The lower surface of the ice is zero depth.

TABLE XXIV.—*Velocities in vertical sections under ice on Catskill Creek.*[a]

Date	Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.	
Station	23.		23.		30.		40.		60.	
Gage height	4.50.		4.96.		4.60.		4.70.		4.80.	
Total depth	4.1.		4.7.		4.5.		5.8.		4.7.	
Thickness of ice	.7.		.5.		1.		1.2.		1.5.	
Depth of water	3.4.		4.2.		3.5.		4.6.		3.2.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.4	1.37	0.3	1.50	0.3	1.42	0.3	2.31	0.3	1
	.9	1.57	.7	1.94	.5	1.84	.7	2.41	.7	1
	1.4	1.57	1.2	1.96	1.0	2	1.1	2.44	1.2	1
	1.9	1.49	1.7	1.89	1.5	2.03	1.0	2.47	1.7	1
	2.4	1.16	2.2	1.79	2.0	1.91	2.1	2.44	2.2	1
	2.9	1.0	2.7	1.62	2.5	1.74	2.6	2.38	2.7	1
	.....	.....	3.2	1.37	3.0	1.55	3.1	2.31	.....	.....
	.....	.....	3.7	1.07	.....	.....	3.6	2.14	.....	.....
	.....	.....	.....	.....	.....	.....	4.1	1.89	.....	.....

[a] Bed of stream rock ledge from 0 to 55, with gravel and silt over remainder of bed.

TABLE XXV.—*Velocities at regular intervals in vertical sections on Catskill Cr under ice, deduced from data in Table XXIV.*

[Velocities in feet per second.]

Depth in feet.	Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent mea
0.05	1.24	94	1.45	92	1.21	69	2.30	101	1.38	
.15	1.42	108	1.82	115	1.85	106	2.42	106	1.66	
.25	1.55	117	1.95	123	1.98	113	2.46	108	1.76	
.35	1.60	121	1.91	121	2.04	117	2.47	108	1.78	
.45	1.56	118	1.86	118	2.03	116	2.44	107	1.71	
.55	1.48	112	1.75	111	1.95	111	2.40	105	1.58	
.65	1.34	102	1.60	101	1.85	106	2.32	102	1.43	
.75	1.19	90	1.42	90	1.72	98	2.20	97	1.22	
.85	1.01	77	1.19	75	1.55	89	2.04	89	1.01	
.95	.81	61	.85	54	1.32	75	1.75	77	.75	
Mean	1.32	100	1.58	100	1.75	100	2.28	100	1.43	

The data contained in Tables XIX and XX have been rearrang and combined in Table XXVI. The mean of the 26 vertical veloci curves taken on the Wallkill is shown in the column headed "Mear The 26 curves are then separated according to the depth of wat under ice at the point whence the observations were taken. In t observations the depth of water was less than 5 feet; in thirteen was from 5 to 10 feet, and in 11 it was from 10 to 20 feet.

To bring out graphically the form of the vertical velocity curve under ice the data in Table XXVI have been plotted in fig. 5, where the solid line represents the mean of the 26 vertical velocity curves taken in the Wallkill. It will be noted that a decided drag occurs at the surface as well as at the bottom of this mean curve; that the maximum velocity occurs at a point about 0.35 of the depth, and that the mean velocity in the vertical occurs at about 0.13 and 0.73 of the depth. There will, in general, always be two points of mean velocity in vertical velocity curves taken under ice.

The results shown in the three last columns in Table XXVI are also plotted in fig. 5, and show the effect of the variation in depth upon the form of the curve. It will be seen that the curves drag more at shallow depths, the curve for depths under 5 feet being more concave than the others, the curve representing the measurements when the water was from 5 to 10 feet in depth being next most concave, while the curve representing the deepest measurement is flattest. This seems reasonable, and would probably hold true in all rivers.

It is frequently desirable to measure the flow of the river when frozen over. This can best be done by taking a large number of point measurements, as represented in fig. 4, but this is a slow process, so that it is important to know at what point the measurement of velocity can be made which will represent the mean velocity in the vertical section.

It will be seen from the four curves in fig. 5 that measurements made at 0.13 and 0.73 of the total depth measured from the bottom of the ice will represent in general the mean velocity in a vertical on a stream with the same general character as the Wallkill. The variation, however, between the curves representing different depths is greater at these two points than at points six hundredths and two-thirds of the depth. At these two points the curves almost coincide. The variation between the various curves was less—in fact within limits only one-half as great—at two-thirds depth as at six-hundredths depth. This shows that in these curves the limit of error is least when measurements are made at two-thirds depth and a coefficient is applied to determine the mean velocity. The mean curve shows a velocity of 105 per cent of the mean at two-thirds depth, so that it would appear that the most accurate method of determining the velocity under ice by observation at one point in the vertical would be to hold the meter at two-thirds depth and apply a coefficient of 0.95 to the observed velocity at that point. This would give a better result than measuring directly the velocity at 0.13 or 0.73 of the depth. In Table XXVII is shown the means of all the curves in the Esopus, Rondout, and Wallkill. These have been plotted in fig. 6. The variation of these three curves is not large, showing that the curve as

plotted represents fairly well the typical velocity curve of riv
this character under ice cover. In Table XXVIII the results
in all the preceding tables, for ice cover, including Wallkill, E
Rondout, and Catskill, have been combined according to de

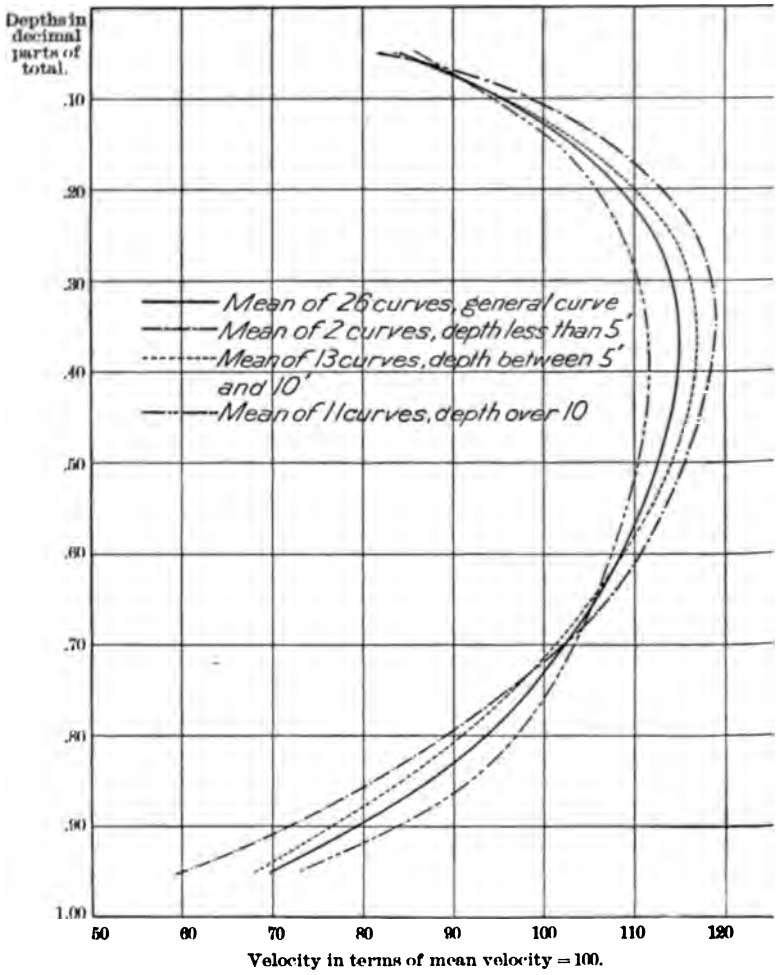
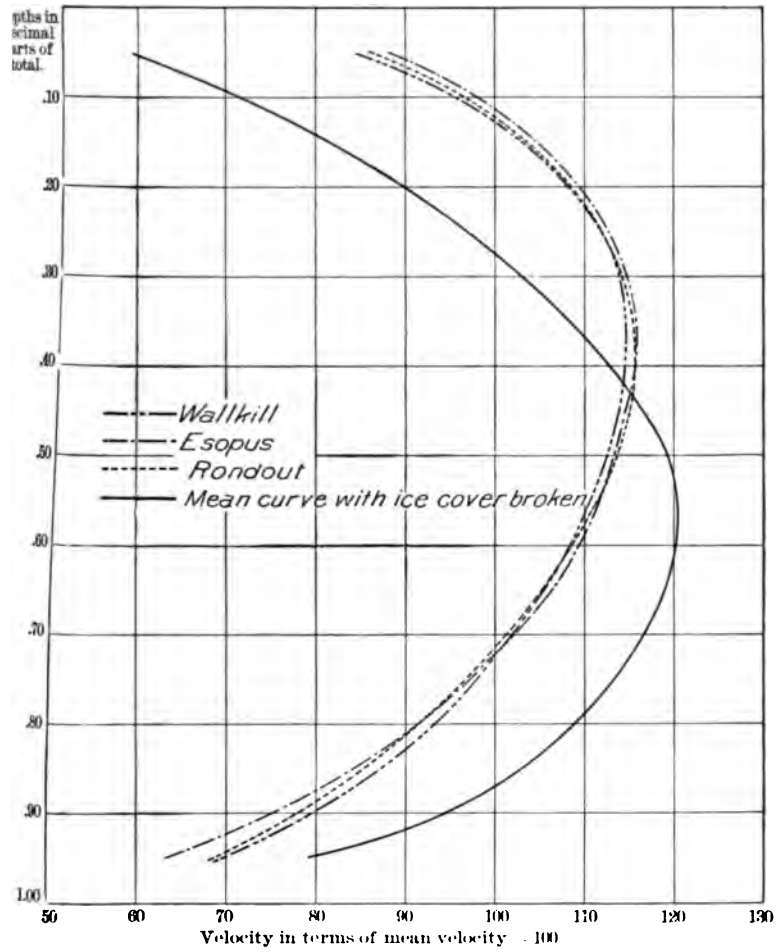


FIG. 5.—Mean vertical velocity curves on Wallkill River, with ice cover, showing t
upon the curve of variation in depth of water.

NOTE.—The solid line is the mean of 26 vertical velocity curves at all depths; the dot-
the mean of two vertical velocity curves at depths less than 5 feet; the dotted line the
13 vertical velocity curves at depths between 5 and 10 feet, and the dash-two-dot lines t
of 11 vertical velocity curves at depths greater than 10 feet.

water under the ice, and have been plotted in fig. 7, together wi
mean of all 47 curves. The form of these curves does not
materially from those for the Wallkill, plotted in fig. 5. The
at which these curves fall closest together is, however, som
higher, at 0.6 depth. To a single measurement made at 0.6 d

efficient of 0.92 should be applied to obtain the mean velocity in the rtical section, while the coefficient 0.95 should be applied to a single easurement made at two-thirds depth, as in the case of the Wall-ll, shown in fig. 5.



. 6.—Mean vertical velocity curves on Esopus and Rondout creeks and Wallkill River, 'ice cover, showing the comparatively slight variation in vertical velocity curves of rivers s character.

'E.—The solid line shows the mean vertical velocity curve on the Wallkill and Rondout he ice broken and tilted, and shows the decided drag caused by the increased friction at rface.

ıere are many engineers who prefer to measure the velocity at depth, and apply a coefficient to obtain the mean velocity in the ical section. The observations recorded in Table XXVII show the proper coefficient to apply is 0.88. Observations upon the of water under ice cover on the Upper Mississippi were made by

A. O. Powell, assistant engineer, under the direction of Col. Chas. J. Allen, Corps of Engineers, U. S. Army, in 1882 and 1890, and the pub-

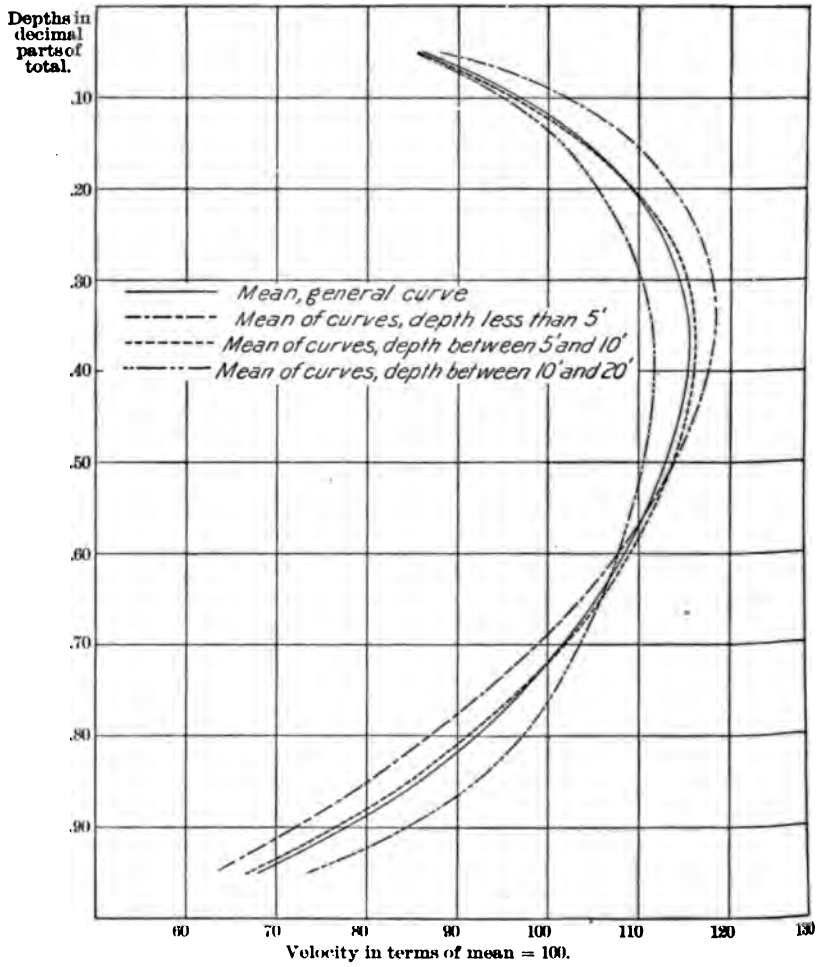


FIG. 7.—Comparison of curves for various depths of water under ice cover with the mean of all curves taken under ice.

NOTE.—The solid line is the mean curve and represents 47 vertical velocity curves. The dash dot line is the mean of 7 curves with depths of water under ice of less than 5 feet. The dotted line is the mean of 29 vertical velocity curves with depths of water under ice ranging from 5 to 1 feet, and the dash-two-dot line is the mean of 11 vertical velocity curves for a depth of wate under ice ranging from 10 to 20 feet.

lished results[a] show that this coefficient varied from 0.87380 t 0.88057.[b]

[a] Ann. Rept. Chief of Engineers, U. S. Army, Part III, 1890.

[b] Owing to the inaccuracies in observations of this kind, it does not seem to the author jus fiable to carry the coefficient beyond the second place of decimals. The results obtained the streams in New York agree with those in the Mississippi to the second place of decimals.

TABLE XXVI.—*Mean vertical velocity curve on Wallkill River and curves separated according to depths of water.*

[Velocities given in percentages of mean velocity.]

Number of velocity curves	26.	2.	13.	11.
		Depth of water under ice.		
Depth below bottom of ice.	Mean.	Less than 5 feet.	Between 5 and 10 feet.	Between 10 and 20 feet.
0.05	84.0	81.5	83.2	85.5
.15	103.0	107.5	103.7	101.5
.25	112.0	117.0	114.0	108.6
.35	114.8	119.0	116.8	111.5
.45	114.0	117.0	115.7	111.4
.55	110.8	113.5	111.8	109.3
.65	105.8	107.5	105.5	105.9
.75	98.4	96.0	96.6	100.9
.85	87.5	81.0	84.5	92.1
.95	69.7	60.0	68.2	73.3
Mean	100.0	100.0	100.0	100.0

TABLE XXVII.—*Mean vertical velocity curves for Esopus, Rondout, and Wallkill, based upon a mean of 100.*

Stream	Esopus.	Rondout.	Wallkill.
Number of velocity curves	8.	8.	26.
Depth below bottom of ice.	Mean.	Mean.	Mean.
0.05	88.2	85.9	84.0
.15	104.7	103.1	103.0
.25	112.9	112.1	112.0
.35	115.9	115.5	114.8
.45	114.6	115.2	114.0
.55	111.8	111.7	110.8
.65	106.8	105.4	105.8
.75	97.4	98.8	98.4
.85	84.6	85.4	87.5
.95	63.1	68.9	69.7
Mean	100.0	100.0	100.0

TABLE XXVIII.—*Mean velocity curves upon Wallkill, Esopus, Rondout, and Catskill for various depths.*

[Velocities given in percentages of mean velocity.]

Number of velocity curves.	7.	29.	11.	47.
Depth below bottom of ice.	Depth of water under ice.			
	Less than 5 feet.	5 to 10 feet.	10 to 20 feet.	Mean of all curves.
0.05	88.0	85.3	85.5	85.
.15	109.6	103.8	101.5	104.
.25	116.7	113.2	108.6	112.
.35	118.4	116.2	111.5	115.
.45	116.1	115.3	111.4	114.
.55	111.0	111.8	109.3	111.
.65	103.7	105.8	105.9	105.
.75	93.2	96.9	100.9	97.
.85	80.3	84.8	92.1	85.
.95	63.0	66.9	73.3	67.
Mean	100.0	100.0	100.0	100.

FLOW OF RIVERS UNDER ICE, BROKEN AND TILTED COVER.

A few vertical velocity curves were taken on the Wallkill and Rondout when the ice on the river was broken and more or less tilted. No general law can be determined for such conditions, as the impeding power of the ice varies between wide limits. It is interesting however, to note in a general way the effect of the ice. The drag at the surface is greatly increased and the curve is changed considerably in form. In Tables XXIX to XXXII will be found the results of the measurements, while in Table XXXIII is the summary of these results. The mean curve, as shown in Table XXXIII, is plotted in fig. 8, together with the mean curves when the ice covering was smooth. It will be seen from this diagram that the point of maximum velocity is 0.55 of the depth, much lower than with smooth ice; that the surface velocity is much less, and that the bottom velocity is greater. This curve would without doubt vary greatly at different times, depending upon the condition of the ice, so that measurements at any point for the determination of the mean velocity would not be advisable. Point measurements at frequent intervals would be necessary in order to obtain reliable results. It is not considered that the results show any decided law of relation between velocities at various depths, but the general form of the curve is characteristic in conditions similar to those under which these were taken.

TABLE XXIX.—*Velocities in vertical section on Wallkill River under ice broken and tilted.*

Date	Dec. 19.		Dec. 19.		Dec. 19.		Dec. 19.		Jan. 23.	
Point of measurement	115.		95.		85.		75.		30.	
Gage height	13.70.		13.70.		13.70.		13.70.		17.33.	
Total depth	18.0.		16.04.		15.64.		14.5.		14.4.	
Thickness of ice	4.0.		0.04.		0.04.		1.0.		1.4.	
Depth of water	14.0.		16.0.		15.6.		13.5.		13.0.	
	Depth.	Velocity.	Depth.	Velocity	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.5	0.30	1.5	2.73	1.1	2.52	1.0	1.52	1.0	1.72
	1.5	1.27	3.5	3.30	3.1	3.08	3.0	2.50	2.5	1.96
	3.5	2.33	5.5	3.48	5.1	3.48	5.0	2.94	4.5	2.26
	5.5	2.71	7.5	3.84	7.1	3.91	7.0	3.03	6.5	2.56
	7.5	2.99	9.5	4.12	9.1	3.95	9.0	3.13	8.5	2.64
	9.5	2.94	11.5	3.93	11.1	3.86	11.0	2.88	10.5	2.24
	11.5	2.84	13.5	3.60	13.1	3.50	13.0	2.45	12.5	1.67
	13.5	1.94	15.5	2.61	15.1	2.64	.....	.....	.....	.....

TABLE XXX.—*Velocities at regular intervals in vertical section on Wallkill River under ice broken and tilted, deduced from Table XXIX.*

Depth in parts of total.	Dec. 19.		Dec. 19		Dec. 19.		Dec. 19.		Jan. 23.	
	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.
0.05	1.10	45	2.35	68	2.40	71	1.40	54	1.68	77
.15	1.94	80	3.00	86	2.95	87	1.94	74	1.88	86
.25	2.41	99	3.35	97	3.33	98	2.60	99	2.07	94
.35	2.70	111	3.65	105	3.62	106	2.87	109	2.26	103
.45	2.90	119	3.90	112	3.86	113	3.04	115	2.45	111
.55	3.00	123	4.10	118	3.95	116	3.11	118	2.62	119
.65	2.94	120	4.07	117	3.90	115	3.08	117	2.62	119
.75	2.80	115	3.88	112	3.76	111	2.98	113	2.44	111
.85	2.55	104	3.60	103	3.42	101	2.78	106	2.15	98
.95	2.05	84	2.85	82	2.80	82	2.50	95	1.80	82
Mean	2.44	100	3.48	100	3.40	100	2.63	100	2.20	100

TABLE XXXI.—*Velocities in vertical sections on Rondout Creek at Rose under ice broken and tilted.*

Date	Dec. 6.		Jan. 14.		Jan. 14.		Jan. 14
Point of measurement	50.		40.		50.		60.
Gage height	6.80.		7.00.		7.00.		7.00.
Total depth	5.6.		4.8.		6.4.		6.4.
Thickness of ice	0.2.		0.8.		0.4.		0.4.
Depth of water	5.4.		4.0.		6.0.		6.0.
	Depth.	Velocity in feet per second.	Depth.	Velocity in feet per second.	Depth.	Velocity in feet per second.	Depth.	V it fe se
	0.3	0.21	0.5	0.35	0.5	0.72	0.5	
	1.3	.54	1.5	.75	1.5	.82	1.5	
	2.8	.55	2.5	.97	2.5	.90	2.5	
	3.8	.57	3.5	.85	3.5	.90	3.5	
	4.9	.36	.....	.....	4.5	.87	4.5	
	.....	.....	.....	.....	5.5	.72	5.5	

TABLE XXXII.—*Velocities at regular intervals in vertical section on Ro Creek under ice broken and tilted, deduced from Table XXXI.*

Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.
0.25	53	0.24	34	0.67	81	0.48	51
.46	99	.40	57	.76	92	.68	72
.54	115	.55	79	.82	100	.87	93
.57	122	.70	100	.88	107	1.06	112
.57	122	.85	121	.90	110	1.19	127
.56	120	.95	136	.91	111	1.19	126
.55	117	.97	139	.90	109	1.14	121
.50	107	.95	135	.88	107	1.06	113
.43	92	.88	126	.82	100	.96	102
.25	53	.51	73	.69	83	78	83
.468	100	.70	100	.823	100	.941	100

TABLE XXXIII.—*Summary of curves on Wallkill and Rondout, under ice broken and tilted.*

Stream	Wallkill.	Rondout.	
Number of velocity curves	5.	4.	9.
Depth of water below bottom of ice.	13 to 16 ft. River bed: Silt.	4 to 6 ft. River bed: Bowlders and gravel.	Mean.
.05	63.0	54.8	59.3
.15	82.6	80.0	81.4
.25	97.4	96.8	97.1
.35	106.8	110.2	108.3
.45	114.0	120.0	116.7
.55	118.8	123.2	120.8
.65	117.6	121.5	119.3
.75	112.4	115.5	113.8
.85	102.4	105.0	103.6
.95	85.0	73.0	79.7
Mean	100.0	100.0	100.0

QUALITY OF RIVER WATER.

A study of the turbidity, color, alkalinity, and hardness of these streams has been made in conjunction with the discharge measurements. It is thought that the information derived from such determinations will be of value to engineers investigating the future supply of New York City.

TURBIDITY AND COLOR.

Water in its ideal condition is perfectly clear and limpid, and has a slightly blue color. Filtered water, distilled water, and many spring waters approach closely to the ideal water. Most river waters are, however, either colored by contact with peat, muck, or decaying vegetation, or are turbid by reason of mud or silt carried in suspension. Muddy waters are often spoken of as colored waters, and in a sense this is correct where the mud consists of clays or other materials having distinct colors, but for convenience of classification it is better to refer to such waters as turbid waters, and to limit the term "colored waters" to those containing in solution vegetable matters which color them.

It has been observed that highly colored waters are usually free from turbidity, and vice versa, this being due to the fact that colored waters usually flow from drainage areas underlain by hard rocks not easily disintegrated, or from regions where the soils are firm or sandy, and especially from swamps. On such areas there is but little material that would be washed from the river banks and held in suspension, while the coloring material is present in the greatest abundance. In many parts of the United States shales or other soft materials

form the underlying beds. These readily disintegrate and form clay soils that are readily washed by hard rains. Waters from such areas are usually turbid and very highly colored.

Turbidity and color are principally important in their effect upon the appearance of water, whereas the other impurities discussed in this paper have absolutely no effect upon the appearance, and can be found only by their chemical action.

TURBIDITY.

The turbidity of water is a subject of great importance to the sanitary engineer. In questions of water supply, turbidity is often the important feature in the selection of a source of town supply; the number of days upon which the turbidity is above a certain fixed standard is also important, in that it may determine the size of reservoir required to store clear water sufficient to tide over the time of greatest turbidity, or for the sedimentation of suspended matters in the reservoir water. The importance of this subject varies with the part of the country studied, the waters in the New England States and New York being comparatively clear, while in the Southern Atlantic States and in the Ohio and Mississippi valleys high turbidities are the rule.

In the Northeast the terms "very slight, "slight," "distinct," and "decided" have been used by analysts to express the amount of suspended matter present. These degrees of turbidity have been estimated by the appearance of the sample to the eye when viewed toward the light. As the importance of these analyses has been more appreciated, particularly in connection with the purification of waters and the extended studies upon waters of high turbidity, it has been found that a more definite scale was necessary in order that proper comparisons of waters from various sources might be made.

In the filtration of water the engineer desires to know the amount of coagulant necessary to properly clarify the water, and it has been found that the turbidity gives a reliable index of the quantity of coagulant required. The object of the more recent studies has been therefore, to express it numerically on some scale, referred to some standard, which can be easily reproduced and will be permanent.

There has been considerable difference of opinion as to the proper standard for turbidity comparisons, and some confusion has resulted. It is important that any standard selected should be applicable to both field and laboratory practice, and that observations made by different methods should be readily comparable.

The United States Geological Survey has had occasion, from time to time, to make observations of turbidity of rivers of which discharge measurements were made. Realizing the importance of a uniform standard for turbidity, the Survey has cooperated with Mr. Allen

Hazen and Mr. George C. Whipple in order that such a standard might be adopted. Mr. Hazen and Mr. Whipple have made joint investigations and studies, and have recommended the standard given below. This will be used in the future by the Survey, and it is hoped may be adopted generally throughout the United States.

PROPOSED TURBIDITY STANDARD.[a]

The standard of turbidity shall be a water which contains 100 parts of silica per million in such a state of fineness that a bright platinum wire 1 millimeter in diameter can just be seen when the center of the wire is 100 millimeters below the surface of the water and the eye of the observer is 1.2 meters above the wire, the observation being made in the middle of the day, in the open air, but not in sunlight, and in a vessel so large that the sides do not shut out the light so as to influence the results. The turbidity of such water shall be 100.

The turbidity of waters more turbid than the standard shall be computed as follows: The ratio of the turbidity of the water to 100 shall be as the extended volume is to the original volume, when the water is diluted with a clear water until the mixture is of standard turbidity.

The turbidities of waters lower than the standard should be computed as follows: The ratio of the turbidity of the water to 100 shall be as the ratio of the original volume of water of standard turbidity is to the extended volume when such water is diluted with a clear water until its turbidity is equal to that of the water under examination.

This standard can be used in both field and laboratory. In the field the wire method will be carried out as at present, except for a new graduation, while in the laboratory the methods of dilution and comparison now in use for the silicia standard will be used.

METHOD OF APPLICATION TO THE PLATINUM-WIRE PROCESS.

A rod with a platinum wire inserted in it at a fixed point and projecting from it at a right angle will be used as at present. The graduation shall be as follows: The graduation mark of 100 shall be placed on the head at a distance of 100 millimeters from the center of the wire. Other graduations will be made, based on the best obtainable data, in such a way that when a water is diluted the readings will decrease in the same proportion as the percentage of the original water in the mixture. Such a rod, having the graduation shown in the table below, shall be known as the United States Geological Survey turbidity rod of 1902. When this rod is immersed in water the visibility of the projecting platinum wire at the depth from the surface shown in the second column will determine the degree of turbidity, as indicated in the first column.

[a] From a letter signed by Messrs. Allen Hazen and George C. Whipple.

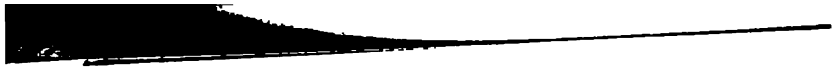
Graduation of rod.

Turbidity.	Depth of wire.	Corresponding value on reciprocal scale.	Turbidity.	Depth of wire.	Corresponding value on reciprocal scale.
	Mm.			*Mm.*	
7	1095	0.023	70	138.0	0.184
8	971	.026	75	130.0	.196
9	873	.029	80	122.0	.208
10	794	.032	85	116.0	.219
11	729	.035	90	110.0	.230
12	674	.038	95	105.0	.242
13	627	.041	100	100.0	.254
14	587	.043	110	93.0	.273
15	551	.046	120	86.0	.295
16	520	.049	130	81.0	.314
17	493	.052	140	76.0	.334
18	468	.054	150	72.0	.35
19	446	.057	160	68.7	.37
20	426	.060	180	62.4	.41
22	391	.065	200	57.4	.44
24	361	.070	250	49.1	.52
26	336	.076	300	43.2	.59
28	314	.081	350	38.8	.65
30	296	.086	400	35.4	.72
35	257	.099	500	30.9	.82
40	228	.111	600	27.7	.92
45	205	.124	800	23.4	1.09
50	187	.136	1000	20.9	1.21
55	171	.148	1500	17.1	1.49
60	158	.160	2000	14.8	1.72
65	147	.172	3000	12.1	2.10

This table is compiled from observations made at Cincinn Louis, New Orleans, Pittsburg, Brooklyn, Philadelphia, and I for records of which we are indebted to several observers. The of the turbidities by the reciprocal scale are included in the t a matter of convenience, but they do not form a part of the sta

This graduation is subject to revision whenever additions shall make it necessary, and revised rods shall be designated same name, but with the year of revision substituted for 1902 revisions shall have as their basis the one hundred mark, 10 meters from the wire.

Near the end of the rod, at a distance of 1.2 meters from th num wire, a wire ring shall be placed directly above the wire, t



hich the observer will look, the object of the ring being to control e distance from the wire to the eye.

When the turbidity is greater than 500 the water should be diluted fore the observation is made. When the turbidity is below 7 this ethod can not be used, and comparison should be made with the lica standard properly diluted in bottles or tubes."

The number obtained by dividing the weight of suspended matter parts per million by the turbidity as obtained above shall be called e coefficient of fineness. If greater than unity, it indicates that the atter in suspension in the water is coarser than the standard; if less han unity, that it is finer than the standard.

This standard is proposed with the idea of combining the best eatures of the platinum-wire and silica methods of measuring turbidities as commonly used, and of avoiding, as far as possible, the bjections to each.

The wire method is most convenient as a field method. With the eciprocal scale, which until now has been used, it is open to the serious objection that the readings are not proportional to the amount of turbidity-producing matter in the water.

The silica standard is free from this objection and is more convenient as a laboratory method, but is not well adapted to field use, and is open to the objection that it is possible that the value may be changed by variations in the fineness of the silica particles composing the standard.

The standard now proposed is intended to overcome the above-mentioned defect in the platinum-wire method with the reciprocal scale, and at the same time to put a control on the value of the silica standard. Applying it in one way or the other, it is adapted to both field and laboratory use, and the results obtained should check substantially.

METHOD OF MAKING OBSERVATIONS.

The method of making the observations by means of the platinum wire is as follows: Take a stick of wood about 5 feet long and five-eighths of an inch square, more or less, and insert a platinum wire at a point about 1 inch from the end, so that the wire will be at right angles to the stick and project at least 1 inch. The wire should be 0.04 inch or 1 millimeter in diameter; the stick is then graduated, the lines for the various turbidities being at distances from the wire shown in the table on page 2.

Observations of turbidity are taken by putting this stick into the water under examination as far as the wire can be seen; the turbidity is then read from the scale. This is most conveniently accomplished by having a second or smaller stick placed in front of the first, the end of which is brought to the water line when the wire can just be

[a] Described by Whipple and Jackson in Technology Quarterly, Vol. XII, No. 4, December, 1899.

seen. Upon removing the two together the position of the smaller stick on the scale gives the turbidity.

Observations are to be taken in all cases in open air, as too high results are obtained under a roof, even with very good light; and they should preferably be taken in the middle of the day and not in direct sunlight. In case the sun is shining the observer can stand so that his shadow covers the water immediately about the stick and wire. The observations are taken with the eye of the observer at the ring before mentioned, 1.2 meters from the wire, although some variation in this does not materially influence the result. The wire should be kept bright and clean. In case it is lost, a clean bright pin can be used until another wire can be obtained. When the surface of the water in the stream is agitated by currents, waves, etc., or in case the depth is not sufficient to give the required immersion, or if for any reason observations can not be well taken from the bank, a pail or tub may be filled with water and the turbidity observations taken in it. In many cases this procedure is preferable to measurement in a stream, but the observation must be taken immediately upon filling the vessel. The diameter of the vessel should be equal to at least twice the depth at which the wire is immersed, as otherwise the results of the reading will be affected.

When the turbidity of the water is above 500, that is, in case the wire can be seen through less than 1 inch of water, the results obtained by direct measurement are not accurate. Such water should be diluted by 1, 2, or 4 volumes of clear water in the pail or tub, and thoroughly mixed.

The turbidity is taken as above described, and multiplied by the ratio that the total volume of water bears to the water in the mixture. Clear water can be obtained from a well or any other source obviously clear, or nearly so.

The statement of turbidity in such cases should contain memoranda that the observations were taken in this way, and should give the amount of dilution.

If waters have a turbidity less than 7 direct reading can not be used, and indirect methods must be resorted to.

The "wire method" has been described first in this paper, as it is best suited to field work. Besides this method, there are two others that have commended themselves to practical use. First, the use of standards of comparison; second, the diaphanometer.[a]

In the determinations of turbidity of waters in rivers considered in this paper, the turbidities were in general too low for accurate measurements by the wire method, and as the samples had to be shipped to the laboratory for other determinations, the turbidity was found by comparison with standards. These standards were made up from dia-

[a] These are both laboratory methods, and have been described by Mr. George C. Whipple and Daniel D. Jackson, in the Technology Quarterly, Vol. XII, No. 4, December, 1899.

tomaceous earth thoroughly washed and ignited to remove the organic matter. The earth is then washed in hydrochloric acid and rinsed with water, after which it is pulverized. One-half grain is added to 500 c. c. of distilled water and thoroughly agitated. This stock mixture contains 1 grain of pure silica per liter, or 1,000 parts per 1,000,000, and when well shaken will always give the same turbidity, which is called a standard 1,000. For waters of low turbidities, like those found in New York State, standards are made by diluting the stock mixture with distilled water in measured proportions and comparing the collected samples with the various standards in gallon bottles, while with higher turbidities smaller quantities of the standards are placed in 100 c. c. Nessler tubes, with which the samples in like tubes are compared. This is a laboratory method, and is more precise than the wire method of making determination of turbidity, but requires that samples be collected and shipped to the laboratory.

In order that some idea of the meaning of the various standards may be obtained, the following table is inserted:

Table showing meaning of various numbers on silica scale.

Silica standard.	Destriptive term.
0	None.
1-2	Very slight.
2-5	Slight.
5-20	Distinct.
Above 20	Decided.

COLOR.

The platinum-cobalt method of measuring color, as devised by Allen Hazen, is generally considered the standard.

A standard solution which has a color of 500 shall be made by dissolving 1.246 grams potassium-platinic chloride[a] ($PtCl_4,2KCl$), containing 0.5 gram platinum, and 1 gram of crystallized cobalt chloride ($CoCl_2,6H_2O$), containing 0.25 gram of cobalt in water, with 100 cubic centimeters concentrated hydrochloric acid, and making up to 1 liter with distilled water. By diluting this solution standards shall be prepared having values of 0, 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, and 70. The numbers correspond to the metallic platinum in the solutions in parts per million. These shall be kept in 100-cubic-centimeter Nessler jars of such diameter that the liquid shall have a depth between 20 and 25 centimeters and shall be protected from dust. The

[a] Potassium-platinous chloride is a salt that is often substituted by dealers in place of the potassium-platinic chloride. It is sometimes incorrectly labeled. The platinous salt has a reddish color while the platinic salt has a yellow color.

color of a sample shall be observed by filling a similar tube and comparing it with the standards. The observation shall by looking vertically downward through the tubes upon a face placed at such an angle that light is reflected upward the column of liquid. The reading shall be recorded to the unit. Waters that have a color darker than 70 shall be diluted making the comparison, in order that no difficulties may be tered in matching the hues. Water containing matter in sus shall be filtered until no visible turbidity remains. If the sus matter is coarse, filter paper may be used for this purpose; if t pended matter is fine, the use of the Berkfeld filter is recomm but it must be thoroughly washed each time before using. T of a Pasteur filter is to be avoided, as it exerts a decolorizing a

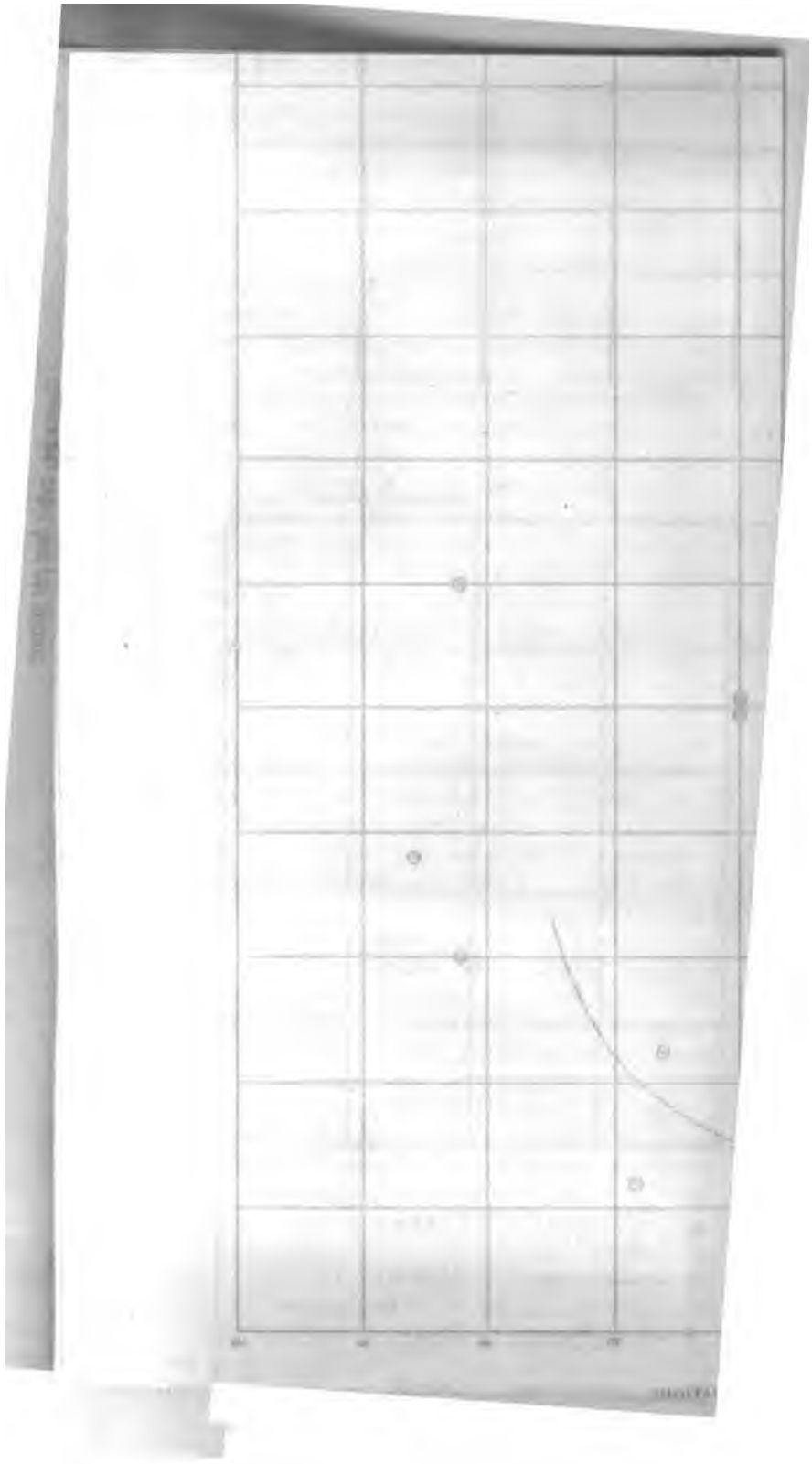
The determinations of color upon the streams considered i paper, and given on the following pages, were made by the laboratory method. For the sake of completeness, however, the method of making determinations of color will be described.

It is impracticable to carry the standard tubes above described the field for observations, and yet field observations are of great venience and value to the sanitary engineer, and in general to investigations of the United States Geological Survey.

Standard disks of colored glass have been prepared by Mr. A Hazen, in cooperation with the Survey, as standards for measur color of water in the field (Pl. X). These disks have been rated Mr. George C. Whipple to correspond with the platinum-cobalt stan ard. The color is measured by balancing the color of the water in metallic tube with glass ends against the colors of glass disks known value. The number on each disk represents the correspon ing color of a water. This is not a new standard, but a new appli tion of an old standard. The glass disks are rated to correspo with the platinum-cobalt color standard. The process bears the sa relation to the usual laboratory process that an aneroid barome bears to a mercurial barometer. The metallic tubes and glass stan ards are more portable and better adapted to field use than the Ness tubes and color solutions previously used.

Color standards.—The standards are disks of amber-colored glas mounted with aluminum. Each disk carries two numbers. O number is over 100, and is a serial number for the purpose of identi fication. The other number is less than 100, and shows the colo value of the disks; that is to say, the color of each disk is equal to the color of a solution of the designated number of parts per million of platinum with the required amount of cobalt to match the hue when seen in a depth of 200 millimeters.

Each apparatus has a series of glass disks of varying values, so that waters within a reasonable range can be matched by them. When a water comes between two disks its value can be estimated



between them by judgment. Two or more disks can be used, one behind the other, in which case their combined value is the sum of the individual values. By combining the disks of a series in different ways a considerable number of values can be produced, allowing the closer matching of many waters.

Filling the tubes.—The tube, having an aluminum stopper, is to be filled with water, the color of which is to be determined. Rinse the tube once or twice by filling and emptying it. The second tube, having the clips to hold the glass disks, is made much like the one holding the water to facilitate comparison. Theoretically this tube should be filled with distilled water. Practically it makes very little difference whether it is filled with distilled water or empty. Use distilled water when it is convenient to do so, and when distilled water of unquestionable quality is at hand; otherwise wipe the inside of the tube dry to prevent fogging of the glass ends, and proceed with the tube empty.

Holding the tubes.—Hold the tubes at such a distance from the eye that the sides of the tubes just can not be seen. This occurs when the near end of the tube is 8 or 9 inches from the eye. Hold the tubes at such an angle that both can be seen at once with one eye. Good results can not be obtained in any other way. Let the tubes change places once or twice, as sometimes the light on the right and left is not quite equal.

Background.—There should be a clear white background with a strong illumination. The best results can not be obtained with either too little or too much light. In a gray day look at the sky near the horizon and away from the sun. In a bright day look at a piece of white paper or tile, upon which a strong light falls. The white surface may be vertical and the tubes held horizontally, or the tubes may be held at an angle directed downward toward a horizontal surface, as may be most convenient. Good results can not be obtained by artificial light.

Turbid water.—The colors of very turbid waters can not be measured in this way. Slight turbidities do not interfere seriously with the results. Waters too turbid for direct observations should be filtered through thick filter paper before being tested, and in case the turbid matter is fine and in large amount even this method may fail. The turbidity of water should be taken as far as possible in connection with color observations, except in cases where it is obvious from inspection that there is practically no turbidity.

Highly colored waters.—Some waters will be found having a higher color than can be matched by the standards. In general, waters with colors above 100 should not be matched in 200-millimeter tubes, and the results with waters having colors below 80 will be considerably more accurate than with more highly colored ones. Two procedures are possible with waters having higher colors—namely, to dilute with dis-

tilled water before measuring the color or to use shorter tubes. latter procedure is the more convenient, but both are equally a rate. To measure the color with short tubes, put the highly col water in a tube of one-half the usual length and match as usual. is not necessary to have a short standard holder. The 200-millim tube can be used. After the water is matched the result is multip by 2. In case the color is too high to be read in a 100-millimeter t it can be put in a 50-millimeter tube, and the result multiplied by When dilution is used the highly colored water is mixed with one more volumes of distilled water, the color matched, and the res multiplied by a corresponding factor. The tube itself can be us for measuring the colored water and the distilled water, and the mi ing can be done in a tumbler or any convenient clean vessel.

Cleaning the tubes.—The tubes should always be kept clean an the glass ends protected. All the ends are removable for the purpo of cleaning, and should not be screwed on too tightly. They shoul be water-tight when only screwed up loosely, and if screwed on har they may stick so as to come off with difficulty.

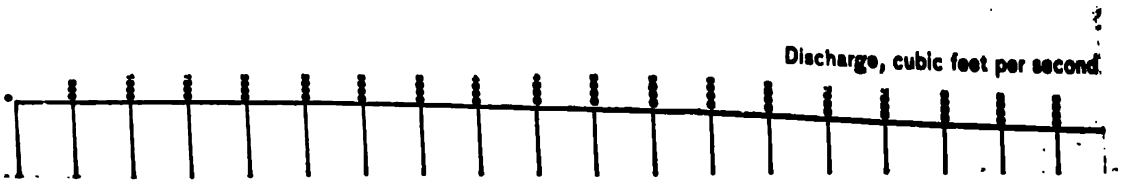
ALKALINITY.

The alkalinity of water is practically a measure of the carbonate and bicarbonates present. The determination is made as follows : Put 100 c. c. of the sample into a 6-inch porcelain evaporating dish. Add two or three drops of a 0.1 per cent aqueous solution of methyl-orange. If the water is alkaline, this will impart to it a faint yellow-ish brown color. Then from a burette graduated in tenths of a cubic centimeter run in a fiftieth-normal solution of sulphuric acid until the color of the water changes to a faint pink. The acid must be added in small portions (only one drop at a time as the end point is reached) and the water stirred with a glass rod after each addition. The number of cubic centimeters of fiftieth-normal acid required, when multiplied by ten, gives the alkalinity of the water expressed in equivalent parts per million of calcium carbonate. That is, if 1.8 c. c. is required to cause the color of the indicator to change from brown to red, then the alkalinity of the water is 18 parts per million. Inasmuch as it is necessary to add a certain amount of fiftieth-normal acid to 100 c. c. of water which has no alkalinity in order to produce the typical color change, the reading obtained must be corrected for this amount. This correction for the indicator varies with different individuals, but it seldom exceeds 0.3 c. c.

Other indicators, such as lacmoid or erythrosine, may be used in place of methyl-orange, and in certain instances their use is to be preferred, but for general field work methyl-orange is most convenient.

PERMANENT HARDNESS.

The Clark's soap method has been used in the examinations of river *waters given in the* following tables. This method gives reliable


Discharge, cubic feet per second

Turbidity, color, alkalinity, and hardness of streams—Continued.

RONDOUT CREEK.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Dis sec
1901.						
Aug. 28	7.15	42	4	37.0	.....	
Sept. 1	7.62	32	20	23.0	.....	
Sept. 3	7.80	66	6	11.0	.....	
Sept. 4	7.13	68	15	18.0	.....	
Sept. 19	6.87	30	12	18.0	.....	
Do	6.87	30	13	14.0	.....	
Oct. 11	6.50	26	4	17.0	.....	
Oct. 3	6.95	40	4	22.0	22.0	
Oct. 15	7.65	26	8	22.0	[a] 21.0	
Oct. 22	6.70	28	3	20.0	[a] 19.0	
Oct. 31	6.50	24	4	24.0	[a] 24.0	
Nov. 13	7.00	21	14	26.0	27.0	
Nov. 16	6.60	26	5	20.0	26.0	
Nov. 19	6.40	21	2	20.0	24.0	
Nov. 22	6.35	23	3	19.0	25.0	
Nov. 26	7.30	32	7	17.0	23.0	
Nov. 29	6.80	31	3	21.0	24.0	
Dec. 3	6.40	23	7	21.0	24.5	
Dec. 6	6.80	21	3	19.0	23.5	
Dec. 10	9.80	32	65	19.0	25.0	
Dec. 11	9.50	38	[b]	13.0	20.0	
Dec. 12	8.50	34	19	12.0	17.5	
Dec. 15	16.70	80	[b]	13.0	18.0	
Dec. 16	11.00	48	75	11.0	20.0	
Dec. 25	7.25	13	7	14.0	26.0	
Dec. 30	12.20	32	60	10.0	20.0	
1902.						
Jan. 7	7.00	17	5	14.0	24.0	
Jan. 14	6.70	14	4	20.0	23.5	
Jan. 18	6.70	14	3	18.0	21.0	
Jan. 23	10.30	32	3	10.0	12.5	
Jan. 25	7.90	23	1	12.0	14.5	
Jan. 28	7.70	80	10	21.0	25.5	
Feb. 4	9.50	14	18	14.5	21.5	
Feb. 11	8.20	11	11	19.5	24.5	
Feb. 14	7.85	10	6	20.0	24.5	
Feb. 27	10.45	22	30	13.0	15.9	

[a] Likely too low.

[b] Bottle broken.

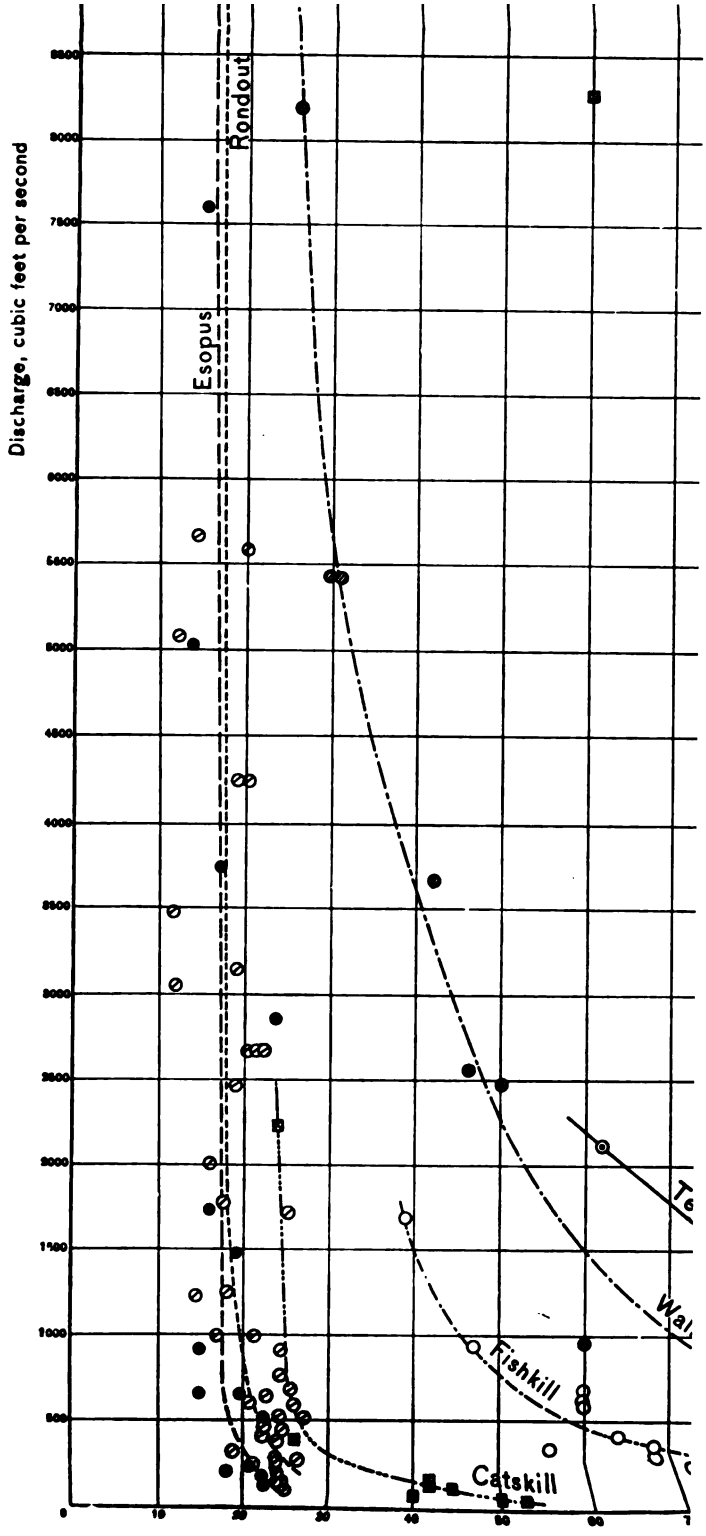


DIAGRAM SHOWING RE

Turbidity, color, alkalinity, and hardness of streams—Continued.

ESOPUS CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
	5.80	20	12	16.0	27.5	4,504
	5.13	10	10	18.0	27.5	2,688
	8.11	35	15	15.0	28.5	1,348
	7.65	23	8	14.0	24.0	1,155
	6.28	21	8	24.0	26.5	550
	4.94	14	6	23.0	25.5	191
	4.49	11	6	34.0	31.0	133

WALLKILL RIVER.

1901.						
	6.75	78	3	77.0		565
	7.2	110	9	48.5		794
	6.25	104	6	58.0		321
	6.05	110	12	64.0		232
	5.85	82	14	62.0		165
	5.95	86	12	71.0		196
	8.55	82	12	65.0		1,503
	7.30	45	13	59.0		814
	6.50	60	7	67.0		440
	6.10	46	5	81.0	93.0	264
	5.94	28	4	92.0	105.0	202
	6.50	45	9	88.0	97.0	440
	[a]11.50	60	45	43.0	50.0	2,480
	13.70	55	38	37.0	42.0	3,680
	20.20	35	45	24.0	26.0	8,190
1902.						
	8.05	33	15	74.0	83.0	717
	16.40	38	125	25.0	30.0	5,422
	7.78	21	14	67.0	76.0	596
	7.30	19	10	89.0	97.2	382
	16.40	31	160	26.0	31.0	5,422
	7.55	29	25	56.0	60.0	977
	10.00	60	28	44.0	46.0	2,540
	6.33	39	8	75.0	89.0	356
	6.40	20	13	73.0	84.0	381
	5.70	33	5	82.0	90.0	126
	7.49	52	23	54.0	72.0	942

[a] Backwater.

Turbidity, color, alkalinity, and hardness of streams—Continued.

WALLKILL RIVER—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge second
1902.						
Aug. 6	7.98	68	25	62.0	71.0	1
Aug. 15	6.72	48	8	83.0	84.0	
Aug. 28	5.86	24	5	88.0	89.0	
Sept. 6	5.78	38	5	57.0	61.0	

TENMILE RIVER.

1901.						
Sept. 12	5.90	13	2	121.0	.....	
Oct. 26	5.00	12	4	134.0	142.0	
Nov. 11	4.75	8	2	146.0	151.0	
Nov. 22	4.80	8	2	147.0	154.0	
Dec. 2	4.75	6	1	137.0	152.5	
Dec. 17	8.41	25	12	79.0	86.0	
Dec. 27	6.54	22	9	103.0	106.0	
1902.						
Jan. 10	5.75	11	4	98.0	103.0	
Feb. 4	6.30	13	11	90.0	104.0	
Feb. 13	5.00	8	6	126.0	137.0	
Mar. 3	[a] 10.41	21	36	60.0	61.1	[b]
Apr. 7	[a] 6.18	12	3	100.0	103.0	
May 2	6.46	19	7	105.0	112.0	
May 15	4.88	12	1	118.0	123.0	
June 9	4.44	16	15	130.0	139.0	
June 30	4.90	19	6	133.0	160.0	
July 21	7.20	40	25	88.0	90.0	
Aug. 4	4.69	11	3	129.0	141.0	
Aug. 19	4.28	10	4	138.0	160.0	
Sept. 2	3.95	10	4	139.0	155.0	

FISHKILL CREEK.

1901.						
Aug. 21	[c] 4.45	39.0	2	88	.....	
Aug. 31	[c] 4.57	24.0	4	85	.....	
Sept. 4	[c] 4.42	24.0	6	88	.....	
Oct. 8	3.90	13.0	3	82	93.0	

[a] All readings on this and following dates made on new gage placed 0.33 foot higher than the old gage.

[b] Approximate.

[c] Taken from daily gage height r

Turbidity, color, alkalinity, and hardness of streams—Continued.

FISHKILL CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Oct. 10	3.85	11.0	2	94	100.0	100
Oct. 17	4.50	36.0	4	72	[a]68.0	305
Oct. 25	4.05	16.0	2	88	[a]84.0	154
Oct. 31	4.00	12.0	3	87	89.0	140
Nov. 5	3.90	12.0	5	85	89.0	113
Nov. 8	3.95	11.0	4	85	92.0	500
Nov. 13	4.35	17.0	4	80	87.0	250
Nov. 15	4.05	21.0	4	78	109.0	154
Nov. 19	3.95	13.0	4	79	94.0	126
Nov. 23	3.90	8.0	4	83	89.0	113
Nov. 26	4.30	22.0	5	74	84.0	233
Dec. 17	6.10	29.0	12	45	47.0	926
Dec. 19	5.10	21.0	7	58	64.0	409
Dec. 24	4.55	11.0	5	71	78.0	224
Dec. 26	4.55	13.0	4	74	79.0	224
Dec. 31	7.30	24.0	12	33	39.0	1,682
1902.						
Jan. 2	5.65	15.0	7	52	60.0	678
Jan. 7	4.80	12.0	3	66	78.0	300
Jan. 9	4.65	11.0	2	70	81.0	[b]258
Jan. 14	5.00	5.0	3	79	83.0	[b]370
Jan. 16	4.35	6.0	5	79	85.0	[b]172
Jan. 21	4.15	6.0	3	82	85.0	[b]128
Jan. 28	4.90	30.0	25	52	55.5	[b]334
Jan. 30	4.95	9.0	4	63	77.0	[b]352
Feb. 4	5.50	13.0	7	53	60.0	[b]594
Feb. 7	5.20	11.0	6	72	82.0	640
Feb. 11	4.80	7.0	4	74	81.0	430
Feb. 18	4.40	5.0	6	80	86.0	268
Feb. 20	4.40	7.0	11	79	87.0	268
Mar. 7	5.20	11.0	14	48	60.0	640
Apr. 18	4.60	10.0	5	63	68.0	345
Apr. 22	4.30	9.5	4	70	72.0	233
Apr. 24	4.10	11.0	3	72	76.0	169
Apr. 29	4.00	13.0	3	79	82.0	140
May 15	3.90	11.0	4	74	85.0	113
May 20	3.80	11.0	3	76	85.0	88
May 22	3.70	13.0	2	79	85.0	66

[a] Likely too low.

[b] Taken from daily gage height record.

Turbidity, color, alkalinity, and hardness of streams—Continued.

WALLKILL RIVER—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge second
1902.						
Aug. 6	7.98	68	25	62.0	71.0	
Aug. 15	6.72	48	8	83.0	84.0	
Aug. 28	5.86	24	5	88.0	89.0	
Sept. 6	5.78	38	5	57.0	61.0	

TENMILE RIVER.

1901.						
Sept. 12	5.90	13	2	121.0	.....	
Oct. 26	5.00	12	4	134.0	142.0	
Nov. 11	4.75	8	2	146.0	151.0	
Nov. 22	4.80	8	2	147.0	154.0	
Dec. 2	4.75	6	1	137.0	152.5	
Dec. 17	8.41	25	12	79.0	86.0	
Dec. 27	6.54	22	9	103.0	106.0	
1902.						
Jan. 10	5.75	11	4	98.0	103.0	
Feb. 4	6.30	13	11	90.0	104.0	
Feb. 13	5.00	8	6	126.0	137.0	
Mar. 3	[a] 10.41	21	36	60.0	61.1	
Apr. 7	[a] 6.18	12	3	100.0	103.0	
May 2	6.46	19	7	105.0	112.0	
May 15	4.88	12	1	118.0	123.0	
June 9	4.44	16	15	130.0	139.0	
June 30	4.90	19	6	133.0	160.0	
July 21	7.20	40	25	88.0	90.0	
Aug. 4	4.69	11	3	129.0	141.0	
Aug. 19	4.28	10	4	138.0	160.0	
Sept. 2	3.95	10	4	139.0	155.0	

FISHKILL CREEK.

1901.						
Aug. 21	[c] 4.45	39.0	2	88	.....	
Aug. 31	[c] 4.57	24.0	4	85	.....	
Sept. 4	[c] 4.42	24.0	6	88	.....	
Oct. 8	3.90	13.0	3	82	93.0	

[a] All readings on this and following dates made on new gage placed 0.33 foot higher than the old gage.

[b] Approximate.

[c] Taken from daily gage height.

Turbidity, color, alkalinity, and hardness of streams—Continued.

FISHKILL CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Oct. 10	3.85	11.0	2	94	100.0	100
Oct. 17	4.50	36.0	4	72	[a]68.0	805
Oct. 25	4.05	16.0	2	88	[a]84.0	154
Oct. 31	4.00	12.0	3	87	89.0	140
Nov. 5	3.90	12.0	5	85	89.0	113
Nov. 8	3.95	11.0	4	85	92.0	500
Nov. 13	4.35	17.0	4	80	87.0	250
Nov. 15	4.05	21.0	4	78	109.0	154
Nov. 19	3.95	13.0	4	79	94.0	126
Nov. 23	3.90	8.0	4	83	89.0	113
Nov. 26	4.30	22.0	5	74	84.0	233
Dec. 17	6.10	29.0	12	45	47.0	926
Dec. 19	5.10	21.0	7	58	64.0	409
Dec. 24	4.55	11.0	5	71	78.0	224
Dec. 26	4.55	13.0	4	74	79.0	224
Dec. 31	7.30	24.0	12	33	39.0	1,682
1902.						
Jan. 2	5.65	15.0	7	52	60.0	673
Jan. 7	4.80	12.0	3	66	78.0	300
Jan. 9	4.65	11.0	2	70	81.0	[b]253
Jan. 14	5.00	5.0	3	79	83.0	[b]370
Jan. 16	4.35	6.0	5	79	85.0	[b]172
Jan. 21	4.15	6.0	3	82	85.0	[b]128
Jan. 28	4.90	30.0	25	52	55.5	[b]334
Jan. 30	4.95	9.0	4	63	77.0	[b]352
Feb. 4	5.50	13.0	7	53	60.0	[b]594
Feb. 7	5.20	11.0	6	72	82.0	640
Feb. 11	4.80	7.0	4	74	81.0	430
Feb. 18	4.40	5.0	6	80	86.0	268
Feb. 20	4.40	7.0	11	79	87.0	268
Mar. 7	5.20	11.0	14	48	60.0	640
Apr. 18	4.60	10.0	5	63	68.0	345
Apr. 22	4.30	9.5	4	70	72.0	233
Apr. 24	4.10	11.0	3	72	76.0	169
Apr. 29	4.00	13.0	3	79	82.0	140
May 15	3.90	11.0	4	74	85.0	113
May 20	3.80	11.0	3	76	85.0	88
May 22	3.70	13.0	2	79	85.0	66

[a] Likely too low.

[b] Taken from daily gage height record.

Turbidity, color, alkalinity, and hardness of streams—Continued.

FISHKILL CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge second
1902.						
May 28	4.55	34.0	5	70	80.0	
June 6	3.50	11.0	3	79	81.0	
June 10	3.80	19.0	4	79	85.0	
June 16	3.50	14.0	5	84	90.0	
June 19	3.50	16.0	5	86	91.0	
July 5	3.60	15.0	4	81	90.0	
July 8	3.50	20.0	2	83	85.0	
July 11	3.40	14.0	3	86	86.0	
July 16	3.10	10.0	2	89	94.0	
Aug. 4	3.60	13.0	2	81	86.0	
Aug. 6	3.40	11.0	3	82	89.0	
Aug. 11	3.60	14.0	12	74	81.0	
Aug. 13	3.60	17.0	2	74	81.0	
Aug. 19	3.20	10.0	3	84	90.0	
Aug. 21	3.10	7.0	2	84	86.0	
Sept. 1	2.90	12.0	4	94	96.0	
Sept. 2	2.80	12.0	5	93	96.0	
Sept. 5	2.90	8.0	3	89	97.0	
Sept. 9	3.00	9.0	3	85	89.0	
Sept. 12	3.05	12.0	3	73	85.0	
Sept. 15	3.20	12.0	2	77	87.0	

HOUSATONIC RIVER.

1901.						
Oct. 29	4.05	19.0	3	103	103.0	
Nov. 13	4.83	25.0	4	102	106.0	
Nov. 23	4.10	21.0	5	100	105.0	
Dec. 28	5.16	14.0	6	91	97.0	
1902.						
Jan. 11	5.00	13.0	5	89	92.0	
Feb. 14	[a]8.30	20.0	5	96	103.0	
Mar. 18	7.63	24.0	.....	53	60.0	
May 3	6.10	20.0	11	78	86.0	
June 22	4.70	24.0	4	89	92.0	
June 23	4.50	18.0	3	92	94.0	
June 25	4.30	14.0	3	93	95.0	

[a] Backwater.

Turbidity, color, alkalinity, and hardness of streams—Continued.

HOUSATONIC RIVER—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
June 26	4.30	15.0	2	94	95.0	1,070
July 2	4.60	18.0	3	90	90.0	1,400
July 4	4.70	20.0	6	91	93.0	1,530
July 6	4.50	16.0	2	93	93.0	1,177
July 8	5.00	22.0	3	91	94.0	2,145
July 15	3.90	14.0	5	85	101.0	750
July 18	3.90	18.0	7	95	98.0	750
July 22	6.70	34.0	22	63	75.0	5,119
July 25	5.60	30.0	12	73	82.0	3,050
July 29	4.90	26.0	7	88	91.0	1,800
Aug. 1	4.80	35.0	4	88	94.0	1,650
Aug. 5	4.20	14.0	4	102	109.0	983
Aug. 8	4.50	14.0	2	102	107.0	1,177
Aug. 12	5.20	32.0	5	73	83.0	2,300
Aug. 15	4.50	31.0	3	85	86.0	1,177
Aug. 19	3.70	11.0	3	96	106.0	
Aug. 22	3.90	11.0	2	96	99.0	750
Aug. 26	3.90	11.0	4	103	107.0	750
Aug. 29	3.90	10.0	3	96	104.0	750
Sept. 2	3.60	10.0	2	98	113.0	640
Sept. 5	3.60	9.0	1	104	110.0	640
Sept. 9	3.40	10.0	1	105	109.0	490
Sept. 12	3.90	13.0	2	97	104.0	750

Though the number of observations is not sufficient to give accurate curves, the results as shown in the tables have been plotted in Pls. IX, XI, XII, and XIII[a] and tentative curves drawn showing the relation of these qualities to the discharge of the stream. In the curves representing alkalinity and hardness the relation seems to be well marked. The diagrams show the relative hardness of the various streams, also ratio of decrease in hardness as the discharge increases. The regularity of the points enables one to prophesy with fair precision the alkalinity or hardness that might be expected at intermediate discharges. The turbidity and color are, as might be expected, far more irregular. It would not be expected that during a rapidly rising flood we should find the same turbidity as at the time of general high water. The

[a] Since the diagrams were plotted many more observations have been obtained and are included in these tables. The diagrams have not been changed, as they are only intended to be suggestive.

effect, too, of a local shower on one tributary may affect the quality of the water much more than the same increase of water from another tributary, so that in an exhaustive study of a large river the effect of floods on each tributary is important, and should be studied rather than the river as a whole. Most of the tributaries of the streams under consideration are short, and storms would usually cover a large part of the drainage basin.

It is not considered that results have been obtained that are final upon these points, so that their publication is in the nature of a progress report. Measurements are being continued, and it is hoped that better curves can be constructed later. The curves representing tur-

FIG. 8.—New folding turbidity stick.

bidity and color are merely suggestions. It was not intended that the color curves of the Catskill and Tenmile should turn so far to the left at the upper part.

GAGE HEIGHTS AND DISCHARGE MEASUREMENTS.

In the following tables are given the mean daily gage heights during the years 1901 and 1902 at the stations established upon the Catskill, Esopus, Rondout, and Fishkill creeks, and Wallkill, Tenmile, and Housatonic rivers.

Following these tables are records of current-meter discharge measurements on these streams. These observations and measurements are being continued.

Mean daily gage height of Catskill Creek at South Cairo, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.55	2.92	2.8	2.7	2.65	17	3.85	2.4	2.82	3.02	2.77	5.0
2	.....	2.6	3.0	2.75	2.7	2.65	18	3.78	2.52	2.97	2.97	2.75	4.4
3	.....	2.55	3.22	2.7	2.65	2.65	19	4.35	2.62	2.97	2.9	2.75	4.0
4	2.75	2.4	3.27	2.7	2.67	3.3	20	3.58	2.67	2.82	2.85	2.75	3.85
5	2.9	2.4	3.05	2.67	2.67	3.3	21	3.17	2.75	2.8	2.82	2.75	3.9
6	3.3	2.5	2.92	2.67	2.65	3.32	22	2.67	3.05	2.8	2.8	2.75	4.0
7	3.6	3.35	2.87	2.62	2.7	3.32	23	2.95	3.22	2.77	2.8	2.7	4.0
8	3.63	3.05	2.9	2.65	2.7	3.3	24	3.0	3.45	2.72	2.8	2.7	4.07
9	3.35	2.87	2.87	2.6	2.65	3.35	25	3.02	3.55	2.67	2.8	2.7	3.45
10	3.07	2.8	2.82	2.65	2.65	5.35	26	2.82	3.2	2.65	2.8	2.7	3.4
11	3.53	2.77	2.8	2.6	2.65	4.62	27	2.7	2.95	2.65	2.75	2.65	3.4
12	3.45	2.65	2.75	2.6	2.67	4.45	28	2.7	2.8	2.7	2.75	2.65	3.5
13	3.23	2.55	2.77	2.65	2.8	3.95	29	2.72	2.7	2.8	2.75	2.65	3.85
14	3.0	2.5	2.72	2.8	3.02	6.95	30	2.65	2.65	2.82	2.7	2.65	4.5
15	2.85	2.5	2.7	3.1	2.85	12.8	31	2.6	2.6	.....	2.7	.....	4.4
16	2.9	2.5	2.75	3.15	2.82	5.6							

Mean daily gage height of Catskill Creek at South Cairo, N. Y., for 1902

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	4.30	11.70	5.35	4.10	2.95	3.48	4.50	2.90	6.18	4.30	3.60
2	.....	5.05	9.68	5.88	3.95	2.88	3.28	5.58	2.83	5.03	4.15	3.63
3	.....	5.20	6.70	4.95	3.93	2.80	3.13	4.38	2.75	5.20	4.05	3.80
4	.....	4.45	6.80	4.88	3.88	2.83	3.10	4.13	2.73	4.80	3.95	4.18
5	4.40	4.40	6.35	4.90	3.83	2.88	3.08	3.85	2.73	4.60	3.90	4.00
6	4.20	4.40	5.40	4.65	3.78	2.88	4.45	4.45	2.70	4.53	3.83	4.00
7	4.05	4.30	4.10	4.40	3.73	2.85	4.20	4.20	2.73	4.40	3.77	3.98
8	4.80	4.25	4.10	4.60	3.70	2.90	3.48	3.93	2.78	4.23	3.73	3.80
9	3.70	4.20	4.30	11.65	3.60	2.80	3.80	3.80	2.90	4.05	3.65	3.70
10	3.55	4.25	5.20	8.25	3.50	2.75	3.65	3.65	3.68	3.90	3.55	4.05
11	3.40	4.40	5.75	6.98	3.40	2.70	3.60	3.55	3.55	3.93	3.50	4.40
12	3.30	4.50	9.10	6.48	3.30	2.65	3.55	3.55	3.28	5.08	3.55	4.13
13	3.30	4.70	9.20	5.50	3.28	2.78	2.95	3.45	3.40	4.60	3.63	4.00
14	3.30	4.95	7.50	4.95	3.23	2.75	2.80	3.15	3.53	4.25	3.53	4.00
15	3.20	3.10	5.45	4.78	3.20	2.70	2.80	3.20	3.35	4.15	3.50	3.95
16	3.30	3.20	7.40	4.58	3.05	2.75	2.75	3.15	3.18	4.25	3.40	4.53
17	3.20	3.40	9.43	4.35	3.00	2.90	2.70	3.05	3.05	3.93	3.40	6.35
18	3.00	3.50	6.85	4.25	2.95	2.88	2.65	2.93	2.95	3.83	3.33	5.43
19	2.90	3.60	4.15	4.20	2.90	2.78	2.70	3.05	2.98	3.80	3.30	5.00
20	2.90	3.80	4.50	4.20	2.95	2.85	4.40	3.10	3.25	3.83	3.28	4.80
21	3.10	3.80	4.00	4.13	2.95	2.80	7.25	3.03	3.48	3.73	3.30	6.65
22	9.85	3.80	4.55	4.10	2.83	2.80	6.50	2.98	3.58	3.73	3.20	8.48
23	5.90	3.50	5.58	4.03	2.78	2.80	6.53	2.93	3.18	3.60	3.20	6.70
24	4.80	3.20	5.48	3.95	2.90	2.78	6.18	2.83	3.10	3.63	3.15	5.13
25	4.40	3.40	5.05	3.90	2.95	2.70	7.08	2.75	3.25	3.60	3.20	4.85
26	4.03	3.50	4.93	3.80	2.85	2.68	7.85	2.70	3.58	3.50	3.30	6.65
27	3.85	4.83	4.83	3.83	3.10	2.65	4.05	2.70	4.35	3.55	3.85	4.35
28	3.58	9.15	5.03	3.73	3.33	2.60	4.20	2.73	a4.70	5.90	4.13	4.20
29	3.70	.....	5.73	3.95	3.25	2.80	4.40	2.85	9.95	5.30	3.80	4.13
30	4.25	.....	5.93	4.10	3.13	3.88	4.38	2.98	7.20	4.70	3.63	3.95
31	4.30	.....	5.43	.....	3.00	.....	4.25	3.08	.....	4.45	.....	3.85

a12 o'clock midnight, 16.1.

Mean daily gage height of Esopus Creek, at Kingston, N. Y., for 1

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	1
1		3.97	6.47	4.52	4.62	4.6	17	4.05	4.37	5.0	4.47	
2		3.95	6.3	4.62	4.52	4.52	18	4.05	4.54	5.27	4.42	
3		3.9	6.67	4.7	4.35	4.77	19	4.6	4.5	5.07	4.6	
4		4.95	6.27	4.52	4.37	5.45	20	4.15	4.77	5.35	4.77	
5	4.3	3.95	5.8	4.42	4.55	4.62	21	4.1	5.95	5.17	4.77	
6	4.35	3.7	5.57	4.3	4.47	4.67	22	3.9	6.62	4.77	4.67	
7	4.3	3.95	5.42	4.47	4.57	4.72	23	4.05	5.92	4.92	4.67	
8	4.4	7.0	5.02	4.57	4.47	4.65	24	4.0	7.35	4.77	4.62	
9	4.4	5.72	5.17	4.5	4.32		25	3.9	7.67	4.5	4.62	
10	4.25	5.17	4.95	4.52	4.32	5.6	26	3.97	6.52	4.37	4.52	
11	4.25	5.05	5.02	4.47	4.45	11.5	27	3.92	6.02	4.5	4.42	
12	4.3	4.87	4.87	4.4	4.57	9.72	28	3.85	5.87	a4.72	4.45	
13	4.3	4.72	4.9	4.5	4.6	7.35	29	3.72	5.72	4.45	4.57	
14	4.2	4.6	4.87	4.52	4.45	8.12	30	4.2	5.45	4.42	4.47	
15	3.95	4.42	4.72	4.57	4.37	21.37	31	4.25	5.22		4.6	
16	4.2	4.42	4.75	4.65	4.43	15.2						

Mean daily gage height of Esopus Creek at Kingston, N. Y., for 1

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	1
1	8.20	7.25	12.10	9.35	8.95	4.85	6.38	7.09	4.45	13.38	
2	10.35	7.45	16.82	8.09	8.18	4.83	6.19	7.95	4.48	11.68	
3	9.95	9.35	15.75	8.05	7.78	4.76	6.00	7.10	4.43	10.10	
4	8.40	7.72	11.07	7.64	7.70	4.83	6.40	6.90	4.33	9.50	
5	7.65	7.52	9.45	7.33	7.43	4.70	5.99	6.53	4.38	8.60	
6	7.30	7.16	8.95	7.03	7.11	4.73	6.19	7.08	4.33	9.64	
7	6.95	6.70	7.90	7.18	6.98	4.55	6.16	6.90	4.38	8.68	
8	6.65	6.47	7.68	7.28	6.74	4.63	6.03	3.43	4.38	8.18	
9	6.50	6.14	8.85	13.10	6.55	4.63	5.80	6.18	4.38	7.85	
10	6.40	6.25	9.20	13.86	6.40	4.68	5.58	5.88	7.68	7.40	
11	6.35	5.94	9.05	11.60	6.23	4.58	5.50	5.83	6.00	7.15	
12	5.88	5.88	9.80	10.22	6.10	4.45	5.34	6.25	5.49	9.10	
13	6.00	5.77	11.85	9.41	5.96	4.53	5.15	5.73	5.53	8.47	
14	5.93	5.60	11.82	8.78	5.88	4.58	5.05	5.58	6.18	8.00	
15	5.60	5.58	9.98	8.25	5.70	4.40	4.98	5.38	5.85	7.60	
16	5.58	5.53	9.33	7.90	5.70	4.46	4.99	5.30	5.53	7.33	
17	5.59	5.63	a18.28	7.58	5.50	4.78	4.89	5.08	5.30	7.15	
18	5.30	5.39	13.10	7.35	5.33	4.94	4.80	5.10	5.13	6.95	
19	5.50	5.45	10.13	7.10	5.38	4.63	4.78	4.98	5.08	6.75	
20	5.37	5.30	9.20	6.93	5.39	4.60	6.88	4.98	5.30	6.73	
21	4.95	5.35	8.62	6.80	5.28	4.81	10.00	4.88	6.88	6.47	
22	12.73	5.36	8.25	6.78	5.13	5.55	9.50	4.85	6.28	6.30	
23	10.88	5.30	8.20	6.93	5.03	5.13	9.28	4.78	5.88	6.20	
24	8.88	5.36	7.87	6.88	5.00	4.93	8.38	4.65	5.68	6.13	
25	8.00	5.39	7.63	6.58	4.88	4.81	8.58	4.70	5.68	6.30	
26	7.53	6.45	7.43	6.36	5.20	4.93	8.68	4.65	7.00	5.87	
27	8.63	9.30	7.28	6.35	5.20	5.15	8.01	4.55	10.35	5.78	
28	8.06	9.37	7.17	6.20	5.58	4.84	7.75	4.65	9.48	7.83	
29	7.72		11.65	5.98	5.25	4.81	7.19	4.70	b22.43	8.35	
30	7.82		12.55	9.81	5.03	7.10	7.68	4.60	17.35	7.75	
31	7.48		10.45		5.03		7.35	4.63		7.50	

a Highest water at 1.30 p. m., 25.25.

b Highest water at 1.30 p. m., 18.80.

Mean daily gage height of Rondout Creek at Rosendale, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	.....	7.57	7.62	7.26	6.5	6.55	17	6.3	6.5	6.67	7.1	6.55	8.95
.....	.....	5.5	7.95	6.85	6.5	6.4	18	6.85	6.75	7.05	7.0	6.55	8.04
.....	.....	6.3	7.8	6.95	6.5	6.5	19	6.55	7.0	6.85	6.9	6.55	7.77
.....	.....	6.25	7.61	6.8	6.45	6.85	20	6.48	6.95	6.65	6.8	6.5	7.55
.....	.....	6.17	7.42	6.7	6.4	6.87	21	6.47	8.75	6.55	6.72	6.4	7.55
.....	.....	6.35	6.97	6.62	6.4	6.85	22	6.37	8.15	6.52	6.7	6.35	7.57
.....	.....	9.75	6.87	6.55	6.4	6.92	23	6.4	7.5	6.47	6.7	6.4	7.95
.....	6.5	7.35	6.77	6.55	6.4	7.0	24	6.35	9.0	6.42	6.6	6.5	7.75
.....	6.4	6.92	6.67	6.52	6.4	7.2	25	6.35	9.4	6.4	6.6	7.6	7.22
.....	6.25	6.62	6.6	6.45	6.4	9.2	26	6.3	8.1	6.35	6.6	7.25	7.12
.....	6.2	7.17	6.6	6.42	6.37	9.25	27	6.47	7.47	6.32	6.6	6.97	7.0
.....	6.25	7.42	6.65	6.42	6.45	8.22	28	6.42	7.15	6.3	6.65	6.87	7.35
.....	6.3	6.87	6.72	6.5	6.95	7.75	29	6.37	6.95	7.05	6.5	6.8	9.1
.....	6.33	6.55	6.57	7.25	6.8	8.97	30	6.67	7.42	7.41	6.5	6.8	12.12
.....	6.3	6.50	6.5	7.72	6.62	16.75	31	6.72	6.72	.....	6.5	.....	10.0
.....	6.38	6.52	6.62	7.37	6.6	10.6							

Mean daily gage height of Rondout Creek at Rosendale, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	9.73	8.98	17.20	8.18	8.25	6.58	7.08	7.70	6.25	10.03	7.25	6.73
.....	7.90	8.95	14.23	7.85	7.70	6.48	6.90	8.35	6.20	9.28	7.05	6.70
.....	7.90	9.75	12.53	7.58	7.70	6.55	6.98	7.60	6.13	8.43	7.03	6.90
.....	7.90	9.35	9.75	7.58	7.75	6.63	7.70	7.28	6.15	7.90	7.00	7.20
.....	7.90	9.70	8.70	7.35	7.50	6.48	7.23	7.08	6.10	7.80	6.90	6.88
.....	7.83	9.25	8.05	7.25	7.33	6.40	7.13	7.25	6.18	8.78	6.87	6.80
.....	7.58	9.00	7.95	7.60	7.28	6.48	7.00	7.33	6.20	8.00	6.95	6.95
.....	7.28	8.83	7.65	8.10	7.15	6.45	6.88	7.03	6.20	7.65	6.85	6.98
.....	7.13	8.58	9.40	12.28	7.03	6.48	6.85	6.93	6.23	7.38	6.80	6.88
.....	7.08	8.05	9.70	11.40	6.93	6.38	6.65	6.83	7.00	7.18	6.78	7.10
.....	7.10	8.18	9.30	9.75	6.88	6.30	6.58	6.80	6.58	6.95	6.73	7.08
.....	7.25	8.05	9.70	9.15	6.88	6.35	6.53	6.10	6.40	9.75	6.73	7.00
.....	6.95	7.98	11.05	8.63	6.83	6.35	6.50	6.80	6.45	8.65	6.73	6.95
.....	6.73	7.88	10.15	8.15	6.68	6.38	6.45	6.70	6.68	8.00	6.70	7.15
.....	6.83	7.80	9.15	7.85	6.63	6.35	6.35	6.55	6.48	7.57	6.70	7.50
.....	6.90	7.65	8.80	7.65	6.70	6.35	6.40	6.58	6.35	7.35	6.70	8.35
.....	6.78	7.53	13.10	7.50	6.60	6.50	6.33	6.50	6.25	7.23	6.65	12.95
.....	6.70	7.60	9.95	7.38	6.63	6.45	6.30	6.45	6.20	7.07	6.65	10.00
.....	6.78	7.35	8.65	7.25	6.60	6.30	6.33	6.40	6.18	7.07	6.68	8.80
.....	6.70	7.43	8.25	7.18	6.60	6.43	7.53	6.40	6.25	7.00	6.65	8.30
.....	6.73	7.43	8.08	7.10	6.58	6.43	8.93	6.38	6.50	6.95	6.65	8.35
.....	14.68	7.40	8.00	7.05	6.50	7.10	9.18	6.48	6.40	6.90	6.65	13.45
.....	9.83	7.43	7.88	7.00	6.48	6.70	8.38	6.40	6.23	6.80	6.60	10.58
.....	8.35	7.48	7.80	6.90	6.45	6.50	[a]9.94	6.40	6.25	6.80	6.60	9.55
.....	7.85	7.55	7.63	6.88	6.46	6.40	10.34	6.33	6.45	6.80	6.55	8.50
.....	7.68	8.23	7.45	6.98	6.80	6.43	8.95	6.30	9.40	6.73	6.70	8.10
.....	8.95	10.68	7.38	6.95	6.88	6.50	8.23	6.28	9.75	6.63	6.75	8.87
.....	7.75	12.10	7.33	6.83	7.20	6.43	7.80	6.25	8.68	9.38	6.90	7.45
.....	8.00	.....	9.85	6.78	6.85	6.45	7.38	6.33	[b]14.09	8.60	6.88	7.27
.....	8.18	.....	9.53	9.38	6.60	7.70	7.80	6.30	10.78	7.83	6.80	7.20
.....	8.60	.....	8.63	.....	6.63	.....	7.33	6.30	.....	7.45	.....	7.20

[a] Highest water, *12.65, at 7 p. m.*

[b] Highest water, 15.6, at 3 p. m.

Estimated diversion from Rondout Creek to Delaware and Hudson Canal, Rosendale, N. Y., 1902, in second-feet.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1				15.5	22.6		24.2	26.0		22.6	22.5	
2				17.7	15.0	25.2	23.8	25.6	25.3	22.4		
3				21.5	24.6	20.8	23.1		22.5	26.1	21.0	
4				22.0		11.6		23.8	24.3	25.8	23.5	
5				17.9	27.6	25.3	24.1	24.5	25.3		21.5	
6					23.1	19.5		22.5	25.8	22.2	23.3	
7				20.4	24.8	21.8	23.1	24.5		23.1	24.2	
8				20.2	24.3		22.7	23.8	25.0	22.4	24.8	
9				18.4	24.6	23.8	24.3	24.0	23.5	21.9		
10				14.3	24.5	35.9	25.3		24.3	22.8		
11				20.7		24.9	26.1	24.0	24.3	22.1		
12				19.2	24.3	33.8	21.8	24.5	25.1			
13					24.1	27.5		24.6	22.2	20.4		
14				25.4	25.0	23.6	25.3	26.0		20.6		
15				25.7	24.1		25.3	24.8	26.5	20.5		
16				24.2	24.5	22.3	24.2	24.5	25.6	19.5		
17				25.1	22.8	22.6	26.0		25.8	19.5		
18				26.1		24.3	25.1	25.5	23.3	19.7		
19				25.6	24.3	23.8	22.7	24.3	24.8			
20					24.6	23.9		23.8	22.0	21.3		
21				25.9	23.1	24.4	23.8	25.1		23.5		
22				26.7	23.6		25.6	25.6	24.3	21.0		
23			15.8	24.1	25.6	22.1	22.8	24.3	23.8	21.2		
24			11.4	23.3	24.3	20.1	20.6		24.0	23.0		
25			12.3	23.4		22.6	19.0	22.8	25.1	20.4		
26			15.3	22.8	21.1	22.8	22.8	22.2	22.8			
27			16.9		28.0	19.8		25.1	22.6	22.8		
28			16.4	27.1	26.5	22.6	25.6	22.5		23.8		
29				25.2	26.3		21.6	25.8	20.3	24.3		
30				25.8	20.7	26.7	23.6	23.0	22.1	23.0		
31			21.8		24.1		26.4			25.0		
Mean				22.5	24.0	23.7	23.8	24.3	24.0	22.2		

Mean daily gage height of Wallkill River at New Paltz, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1		6.10	9.20	7.45	6.00	6.25	17	6.37	6.75	7.05	7.50	6.25	13.10
2		5.90	9.85	7.25	6.00	6.05	18	7.15	9.25	7.02	7.27	6.05	13.05
3		5.97	9.75	7.15	6.00	6.00	19	7.98	11.15	7.65	7.15	6.15	13.75
4		6.00	9.35	7.00	6.00	6.20	20	7.20	10.15	7.45	6.95	6.35	12.95
5		6.45	8.55	6.95	6.05	6.35	21	6.50	10.25	7.30	6.70	7.30	11.70
6		6.45	8.35	6.85	6.10	6.65	22	6.35	10.25	7.10	6.45	8.10	10.70
7	7.27	12.05	8.05	6.65	6.00	6.60	23	6.25	10.15	6.95	6.32	8.65	10.45
8	7.23	11.25	7.70	6.47	5.95	7.30	24	6.05	9.70	6.82	6.30	8.35	10.15
9	6.93	9.30	7.47	6.35	5.85	10.00	25	6.00	14.30	6.65	6.20	8.10	9.85
10	6.65	9.15	7.45	6.30	5.75	12.30	26	6.00	12.00	6.50	6.12	7.45	9.60
11	6.53	9.10	7.25	6.30	5.65	11.70	27	5.85	11.25	6.35	6.10	6.95	9.35
12	7.33	8.05	7.05	6.20	5.95	10.30	28	5.85	10.60	6.35	6.10	6.85	9.70
13	7.00	7.70	7.15	6.20	6.40	10.05	29	5.85	9.90	6.65	6.10	6.65	11.60
14	7.15	7.15	6.95	6.35	7.00	10.00	30	5.80	9.15	7.25	6.10	6.45	13.25
15	6.85	7.40	6.65	7.50	6.90	13.30	31	5.95			6.50		13.20
16	6.55	7.10	6.75	7.85	6.55	12.85							

Mean daily gage height of Wallkill River at New Paltz, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	15.15	8.75	23.53	9.35	10.25	7.50	7.25	9.50	6.10	10.25	8.65	6.80
.....	13.25	8.75	23.80	8.95	8.95	7.25	7.15	9.10	6.05	10.85	8.35	6.70
.....	12.95	10.65	a24.65	8.65	9.15	7.05	7.50	8.75	6.00	10.15	8.15	7.50
.....	12.10	9.70	22.75	8.20	8.85	6.90	7.58	8.60	5.88	9.65	7.95	7.95
.....	10.45	9.75	20.25	8.00	8.35	6.55	7.08	8.30	5.78	9.60	7.65	8.10
.....	10.70	8.90	15.20	9.70	7.95	6.35	6.78	7.95	5.70	10.10	7.50	8.55
.....	10.20	8.15	13.20	7.70	7.50	6.30	6.53	7.85	5.60	9.45	7.50	8.10
.....	8.70	7.85	12.70	8.40	7.45	6.25	6.35	7.65	5.50	9.00	7.65	7.70
.....	9.15	7.78	14.90	b13.65	7.35	6.30	6.23	7.30	5.50	8.55	7.15	7.70
.....	8.85	7.70	16.45	13.50	7.10	6.50	6.10	7.05	6.10	8.40	6.95	7.65
.....	8.75	7.55	15.90	12.20	6.80	6.35	6.00	6.90	6.45	8.25	6.75	7.60
.....	8.20	7.55	16.10	11.65	6.65	6.30	6.00	6.80	6.30	12.45	6.70	7.60
.....	8.05	7.40	17.05	10.65	6.60	6.20	5.90	6.75	6.35	11.90	6.60	7.55
.....	8.05	7.35	16.50	9.80	6.55	6.15	5.78	6.68	6.45	10.50	6.60	7.50
.....	8.00	7.15	15.00	9.35	6.50	6.10	5.70	6.60	6.25	9.70	6.60	7.50
.....	8.00	7.10	14.65	8.65	6.45	6.20	5.70	6.53	6.15	9.35	6.50	7.50
.....	7.70	7.20	15.40	8.20	6.35	6.25	5.73	6.43	6.05	9.00	6.50	12.20
.....	7.55	7.15	13.75	8.00	6.30	6.15	5.58	6.38	5.95	8.60	6.50	12.25
.....	7.50	7.08	11.75	7.85	6.30	6.13	5.55	7.28	5.80	8.60	6.50	12.30
.....	7.20	7.00	10.60	7.60	6.30	6.10	6.10	6.20	5.90	8.15	6.50	12.30
.....	7.20	7.05	10.30	7.45	6.30	6.13	7.78	6.15	5.90	7.95	6.40	12.95
.....	18.50	7.05	10.20	7.35	6.30	6.33	8.65	6.10	5.90	7.65	6.40	19.00
.....	17.65	7.10	9.75	7.15	6.25	6.40	7.40	6.05	5.90	7.47	6.65	19.65
.....	13.55	7.25	9.60	7.10	6.20	6.35	c11.00	6.10	5.90	7.37	6.30	17.20
.....	13.15	7.30	9.45	6.95	6.20	6.20	d14.00	6.05	6.15	7.15	6.30	16.25
.....	12.20	7.75	9.00	6.85	6.45	6.20	9.10	6.00	9.65	6.95	6.85	15.30
.....	12.85	11.40	8.50	7.00	8.30	6.10	8.50	6.00	12.00	6.85	7.35	14.20
.....	12.65	12.75	8.20	6.75	9.20	6.03	7.80	5.95	11.90	11.65	7.35	14.20
.....	11.15	.....	10.20	6.65	8.40	6.13	7.45	8.25	13.45	11.25	7.10	13.80
.....	9.50	.....	11.05	e11.75	8.30	7.00	7.45	6.95	10.35	9.45	6.95	12.30
.....	9.25	.....	9.90	.....	7.90	.....	8.45	6.40	.....	8.95	.....	11.75

st water 24.80 at p. m. c Highest water 15.4 at 8 p. m. e Highest water 12.6 at p. m.
st water 14.6 at p. m. d Highest water 16.6 at 9 p. m.

Mean daily gage height of Fishkill Creek at Glenham, N. Y., for 1901.

	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	.....	3.95	4.57	4.05	3.97	3.90	17	3.73	3.85	4.15	4.55	3.95	6.18
.....	.....	3.82	4.60	3.97	3.95	3.98	18	4.23	5.07	4.22	4.40	3.95	5.53
.....	.....	3.77	4.47	4.10	3.95	4.05	19	4.00	4.70	4.12	4.32	3.95	5.15
.....	.....	3.67	4.42	4.10	3.95	4.08	20	3.90	4.40	4.02	4.22	3.95	4.98
.....	.....	3.65	4.30	4.00	3.90	4.10	21	3.77	4.45	4.02	4.20	3.93	4.78
.....	.....	3.65	4.15	3.92	3.90	4.25	22	3.70	4.95	4.00	4.15	3.93	4.73
.....	.....	4.70	4.17	3.90	3.92	4.28	23	3.65	4.62	3.92	4.12	3.90	4.73
.....	3.90	5.55	4.10	3.87	3.95	4.18	24	3.65	4.70	3.90	4.10	3.90	4.55
.....	3.90	4.77	4.07	3.85	3.90	4.05	25	3.65	6.40	3.87	4.05	4.35	4.60
.....	3.80	4.35	4.02	3.85	3.87	4.73	26	3.62	6.55	3.85	4.00	4.38	4.56
.....	3.78	4.12	4.05	3.85	3.87	5.33	27	3.60	5.65	3.80	4.00	4.13	4.85
.....	3.83	4.07	4.37	3.80	3.92	4.83	28	3.45	5.20	3.87	4.00	4.03	4.15
.....	3.80	4.02	4.32	3.80	4.32	4.60	29	3.57	4.85	3.95	4.00	4.00	5.75
.....	3.73	3.90	4.15	4.30	4.17	4.68	30	4.35	4.70	4.20	4.00	3.98	8.28
.....	3.70	3.90	4.10	4.85	4.05	6.78	31	4.15	4.57	.....	3.97	.....	7.50
.....	3.65	3.82	4.25	4.82	4.00	7.45							

Mean daily gage height of Fishkill Creek, at Glenham, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	6.05	5.00	13.00	4.90	5.48	3.83	3.70	3.80	2.90	4.25	4.40
2	5.65	4.75	10.00	4.78	4.93	3.70	3.53	3.70	2.80	4.20	4.33
3	5.50	5.63	8.78	4.68	4.70	3.60	3.45	3.60	2.95	4.00	4.20
4	5.90	5.55	6.70	4.60	4.73	3.70	3.85	3.60	2.73	3.83	4.15
5	5.18	5.58	5.80	4.53	4.63	3.70	3.60	3.50	2.90	3.83	4.05
6	4.95	5.28	4.95	4.45	4.45	3.55	3.70	3.43	2.95	4.20	4.08
7	4.80	5.25	5.05	4.53	4.35	3.50	3.70	3.48	2.90	4.20	4.00
8	4.70	5.00	5.15	4.63	4.30	3.85	3.55	3.40	2.95	3.93	4.00
9	4.65	5.18	5.90	5.13	4.20	3.85	3.45	3.40	3.00	3.85	3.98
10	4.63	5.05	7.75	5.65	4.10	3.75	3.38	3.30	3.33	3.78	3.90
11	4.60	4.75	6.95	5.53	3.90	3.60	3.40	3.50	3.25	3.70	3.88
12	4.58	4.80	6.50	5.28	3.98	3.50	3.30	3.85	3.08	4.95	3.88
13	4.75	4.60	6.70	5.05	3.95	3.40	3.23	3.65	3.30	5.08	3.88
14	5.00	4.40	6.63	4.90	3.90	3.43	3.20	3.48	3.23	4.08	3.88
15	4.70	4.33	5.98	4.80	3.90	3.50	3.13	3.40	3.20	4.35	3.80
16	4.35	4.25	5.65	4.70	3.90	3.50	3.13	3.35	3.15	4.20	3.83
17	4.28	4.48	6.73	4.60	3.80	3.95	3.10	3.28	3.15	4.80	3.80
18	4.25	4.38	6.45	4.58	3.70	3.70	3.10	3.20	3.18	4.00	3.70
19	4.25	4.33	5.70	4.50	3.75	3.50	3.08	3.20	3.00	4.00	3.70
20	4.18	4.35	5.20	4.40	3.80	3.53	3.20	3.15	3.05	3.95	3.68
21	4.18	4.38	5.30	4.35	3.83	3.50	4.15	3.10	3.08	3.90	3.68
22	5.88	4.85	5.23	4.30	3.68	3.75	4.70	3.15	3.15	3.80	3.60
23	6.55	4.85	5.13	4.23	3.68	3.60	4.65	3.10	3.08	3.80	3.60
24	5.15	4.90	5.00	4.15	3.60	3.50	4.10	3.10	3.13	3.70	3.63
25	4.75	4.70	4.85	4.05	3.60	3.40	4.18	3.15	2.95	3.75	3.63
26	4.63	4.85	4.75	4.05	4.20	3.50	4.10	3.05	3.48	3.73	3.68
27	5.00	5.88	4.70	4.13	4.15	3.40	4.05	3.00	3.60	3.70	3.95
28	5.00	7.10	4.55	4.08	4.58	3.30	3.90	3.00	3.60	4.65	3.88
29	4.95	.....	4.85	4.00	4.23	3.35	3.80	2.95	4.80	5.43	3.80
30	5.05	.....	5.40	4.83	4.03	4.08	4.20	2.95	4.75	4.93	3.70
31	4.95	.....	5.05	.....	3.90	.....	3.95	2.90	.....	4.55	.....

Mean daily gage height of Tenmile River at Dover Plains, N. Y., for 1901.

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	D
1		5.02	4.95	4.65	17	5.00	6.17	5.05	
2		4.80	4.90	4.67	18	5.30	5.87	5.90	
3		5.00	4.90	4.95	19	5.00	5.62	4.87	
4		5.00	4.85	5.50	20	4.85	5.50	4.87	
5		4.87	4.87	6.05	21	4.80	5.47	4.85	
6		4.85	4.87	5.40	22	4.80	5.40	4.79	
7		4.75	4.85	5.02	23	4.70	5.35	4.75	
8		4.65	4.80	4.80	24	4.60	5.27	4.75	
9		4.65	4.77	4.77	25	4.57	5.20	5.20	
10		4.65	4.75	6.35	26	4.50	5.00	5.10	
11		4.65	4.67	6.72	27	4.55	5.02	4.90	
12		4.65	4.97	6.35	28	4.37	5.05	4.95	
13		4.57	5.90	6.12	29	4.77	4.97	4.85	1
14		6.27	5.50	6.47	30	5.50	4.95	4.72	1
15		6.82	5.27	11.17	31		4.92	.....	1
16		6.42	5.10	9.50					

ıı daily gage height of Tenmile River at Dover Plains, N. Y., for 1902.

y.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	7.70	5.40	14.15	6.60	6.95	4.55	4.45	5.10	3.90	5.78	5.75	4.45
.....	7.00	6.10	14.10	6.45	6.95	4.50	4.25	4.88	3.83	5.85	5.50	4.48
.....	6.95	6.95	a11.43	6.25	6.50	4.40	4.35	4.65	3.80	5.43	5.43	4.80
.....	6.10	6.08	8.35	5.98	6.20	4.55	5.53	4.63	3.90	5.10	5.33	4.90
.....	6.08	5.50	6.95	5.80	6.05	4.48	4.38	4.53	3.83	5.30	5.30	4.73
.....	6.15	5.35	5.90	5.90	5.90	4.35	4.60	4.43	3.80	5.85	5.25	4.78
.....	6.10	5.10	6.25	6.13	5.75	4.25	4.63	4.65	3.85	5.38	5.10	4.80
.....	5.80	5.10	6.25	6.40	5.55	4.48	4.33	4 60	3.88	5.13	5.08	4.85
.....	5.65	4.95	8.90	6.80	5.35	4.55	4.38	4.45	3.95	4.90	5.00	5.13
.....	5.55	4.90	10.60	7.60	5.23	4.48	4.23	4.43	4.23	4.83	4.98	5.08
.....	5.60	5.10	9.15	7.10	4.95	4.30	4.20	5.68	3.95	5.00	4.83	4.85
.....	5.55	5.10	8.70	6.60	4.85	4.20	4.10	5.03	3.90	6.10	4.78	4.80
.....	5.38	4.80	9.10	6.30	4.85	4.75	4.15	5.95	4.10	6.93	4.83	4.80
.....	5.25	6.75	8.40	6.15	4.80	4.70	3.90	4.78	4.23	5.87	4.80	4.98
.....	5.25	5.25	7.70	6.10	4.80	4.35	3.88	4.68	4.13	5.63	4.88	5.08
.....	4.98	5.15	7.30	5.90	4.75	4.45	4.30	4.23	4.03	5.43	4.73	6.15
.....	4.65	5.05	8.15	5.88	4.65	4.65	4.18	4.18	3.88	5.25	4.65	10.47
.....	5.05	5.05	7.60	5.68	4.60	4.45	3.88	4.15	3.88	5.15	.....	9.13
.....	5.10	5.00	6.55	5.58	4.65	4.28	4.08	4.15	4.08	5.27	4.60	8.28
.....	5.05	4.85	6.13	5.45	4.68	4.15	4.65	4.18	4.28	5.20	4.53	7.70
.....	5.05	4.75	6.10	5.35	4.58	4.40	6.98	4.25	4.33	4.90	4.55	7.74
.....	11.95	4.68	6.15	5.23	4.50	4.60	7.15	4.23	4.13	4.80	4.58	11.50
.....	8.10	4.40	6.20	5.13	4.40	4.38	6.35	4.10	4.15	4.75	4.55	10.65
.....	6.35	4.50	6.25	5.08	4.30	4.33	5.75	4.08	4.08	4.73	4.53	8.58
.....	5.80	4.65	6.05	4.95	4.30	4.15	5.68	4.08	4.05	4.65	4.58	7.95
.....	5.70	5.63	5.90	4.95	5.05	4.10	5.50	3.98	4.08	4.55	4.70	7.48
.....	7.80	8.45	5.85	5.30	5.30	4.05	5.30	3.98	4.65	4.60	4.93	7.05
.....	7.45	9.73	7.43	5.25	5.50	4.05	5.40	3.85	6.50	7.05	4.78	.....
.....	6.55	.....	7.60	5.30	5.18	4.10	5.25	3.83	7.75	7.10	4.65	.....
.....	6.25	.....	7.30	7.00	4.80	4.70	5.65	3.80	5.98	6.37	4.33	.....
.....	5.80	.....	6.90	.....	4.70	.....	5.25	3.85	.....	6.00	.....	.....

a Readings on new gage from this date, datum 0.33 above former gage.

Daily gage height of Housatonic River at Gaylordsville, Conn., for 1900.

Day.	Oct.	Nov.	Dec.	Day.	Oct.	Nov.	Dec.
.....	.....	3.2	4.9	17.....	.....	3.6	.....
.....	.....	3.1	4.6	18.....	.....	3.5	.....
.....	.....	3.1	4.3	19.....	.....	3.6	.....
.....	.....	2.9	4.2	20.....	.....	3.7	.....
.....	.....	3.0	5.6	21.....	.....	4.1	.....
.....	.....	2.9	5.8	22.....	.....	4.0	.....
.....	.....	2.8	5.4	23.....	2.9	3.9	4.8
.....	.....	3.2	5.1	24.....	3.1	3.9	5.1
.....	.....	3.5	4.9	25.....	3.2	3.8	4.3
.....	.....	4.1	4.5	26.....	3.1	4.6	4.2
.....	.....	3.9	4.2	27.....	3.1	5.5	4.1
.....	.....	3.7	4.2	28.....	3.1	5.4	4.2
.....	.....	3.6	4.2	29.....	3.1	5.1	4.0
.....	.....	3.7	4.2	30.....	3.0	4.9	3.9
.....	.....	3.7	.....	31.....	.....	.....	4.2
.....	.....	3.7	.....				

Daily gage height of Housatonic River at Gaylordsville, Conn., for 1901

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	4.40	3.20	3.30	5.30	6.20	6.20	3.60	3.50	4.30	4.30	4.00
2	4.00	3.30	3.50	5.30	6.20	6.00	3.50	3.70	4.40	4.20	4.20
3	(a)	3.30	3.60	5.30	6.40	5.70	3.80	3.50	4.70	4.50	4.00
4	(a)	3.30	3.60	6.10	6.30	5.50	3.90	3.40	4.60	4.60	3.80
5	(a)	3.10	4.10	6.60	6.00	5.50	3.70	3.30	4.60	4.40	3.70
6	4.50	3.00	3.90	6.50	5.60	5.20	4.00	3.30	4.40	4.20	4.10
7	4.50	3.40	3.90	7.30	5.50	5.20	4.00	3.90	4.40	4.00	3.80
8	4.40	3.50	3.60	8.30	5.30	5.50	3.80	4.80	4.40	3.90	3.80
9	4.20	3.40	3.50	8.00	5.20	5.50	3.80	4.40	4.00	4.00	3.80
10	4.40	3.70	7.50	7.80	5.20	5.40	3.80	4.10	3.90	4.00	3.70
11	4.10	3.50	8.20	7.20	5.70	5.20	3.90	4.00	4.00	3.80	3.50
12	4.70	3.30	7.50	6.70	6.30	4.90	4.00	3.90	4.20	3.80	3.60
13	4.00	3.40	6.00	6.50	6.10	4.80	4.00	3.70	4.00	3.80	4.80
14	3.50	3.70	5.50	6.10	6.00	4.60	3.90	3.70	4.00	5.20	4.90
15	3.70	3.60	5.60	5.90	5.60	5.20	3.60	3.60	4.00	6.70	4.70
16	3.80	3.40	5.60	5.90	5.50	4.70	3.50	3.70	4.10	6.00	4.60
17	4.40	3.40	4.60	5.50	5.30	4.50	3.70	3.60	4.10	5.80	4.50
18	4.00	3.40	4.60	5.30	5.30	4.20	3.60	3.70	4.70	5.30	4.40
19	3.50	3.20	4.80	5.20	5.80	4.30	3.60	4.00	4.50	5.10	4.20
20	3.40	3.30	4.80	5.20	6.20	4.20	3.60	3.80	4.40	4.90	4.30
21	3.80	3.40	10.00	7.30	6.20	4.10	3.60	4.10	4.20	4.80	4.20
22	3.60	3.50	8.70	9.30	5.80	4.00	3.50	4.70	4.20	4.60	4.20
23	3.70	3.40	7.40	8.40	5.80	4.30	3.40	4.80	4.00	4.50	4.10
24	3.50	3.20	7.10	8.50	5.60	4.70	3.60	4.80	3.80	4.40	4.20
25	3.60	3.30	6.60	8.80	6.80	4.60	3.60	6.80	3.90	4.30	4.60
26	3.70	3.00	6.60	7.85	6.70	4.30	3.50	6.70	3.80	4.30	4.80
27	3.80	3.40	7.20	7.20	6.80	4.20	3.50	5.70	3.80	4.20	4.50
28	3.70	3.30	6.90	6.90	6.80	4.00	3.50	5.20	3.80	4.00	4.00
29	3.50	.....	6.60	7.00	6.90	4.00	3.50	4.80	3.90	4.00	4.00
30	3.50	.....	6.20	6.40	6.80	3.80	3.40	4.60	4.40	4.30	4.20
31	3.40	.....	5.80	.....	6.60	.....	3.70	4.40	.....	4.10	.....

a Frozen.

daily gage height of Housatonic River at Gaylordsville, Conn., for 1902.

ay.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	7.10	4.90	14.30	6.80	6.80	4.70	4.80	4.80	3.80	5.50	5.50	4.10
.....	6.50	4.90	10.80	6.60	6.30	4.40	4.60	4.65	3.55	5.50	5.30	4.15
.....	5.90	5.40	9.90	6.80	6.10	4.40	4.40	4.65	3.50	5.25	5.00	4.40
.....	5.30	4.90	10.20	5.80	5.90	4.60	4.70	4.45	3.60	5.15	4.95	4.60
.....	5.20	4.80	7.80	5.80	5.60	4.90	4.50	4.30	3.65	5.00	4.85	4.60
.....	5.30	4.60	6.80	5.50	5.50	4.80	4.50	4.40	3.55	5.15	4.75	4.30
.....	5.30	4.50	6.50	5.50	5.50	4.60	4.80	4.60	3.65	5.00	4.65	4.35
.....	5.20	4.40	6.80	5.70	5.30	4.60	5.00	4.55	3.50	4.85	4.60	4.30
.....	5.30	8.50	6.80	6.10	5.20	4.40	4.70	4.55	3.55	4.70	4.50	3.45
.....	5.10	6.80	7.50	6.80	4.90	4.60	4.50	4.45	4.00	4.55	4.35	3.55
.....	5.00	7.00	2.20	6.90	5.00	4.50	4.40	4.50	4.00	4.40	4.30	3.70
.....	4.90	8.00	7.70	6.80	4.90	4.50	4.30	5.15	3.90	5.30	4.45	3.75
.....	4.70	8.80	7.80	6.80	4.90	4.40	4.20	5.00	3.85	5.30	4.40	4.00
.....	4.30	8.30	8.00	6.70	4.80	4.70	4.00	4.70	4.10	5.10	4.50	4.05
.....	4.50	8.00	7.90	6.20	4.70	4.60	3.90	4.50	4.00	5.00	4.50	4.25
.....	4.50	7.10	7.70	5.90	4.60	4.30	4.10	4.35	3.60	4.80	4.40	4.90
.....	4.30	6.80	7.90	5.80	4.60	4.50	4.20	4.20	3.70	4.75	4.35	7.90
.....	4.20	7.00	7.60	5.60	4.50	4.40	3.90	4.00	3.75	4.60	4.25	7.35
.....	4.40	7.50	7.30	5.60	4.40	4.40	3.80	3.80	3.80	4.55	4.30	6.70
.....	4.20	7.30	7.00	5.50	4.30	4.40	4.65	4.05	3.85	4.25	4.25	6.35
.....	4.50	7.20	6.60	5.20	4.60	4.30	6.00	3.95	4.05	4.30	4.30	6.65
.....	8.50	7.20	6.60	5.20	4.40	4.70	6.60	4.05	3.75	4.45	4.20	8.60
.....	6.80	6.80	6.10	5.10	4.30	4.50	6.00	4.10	3.60	4.40	4.20	8.40
.....	6.30	6.50	5.90	5.10	4.10	4.30	5.70	4.10	3.70	4.45	4.05	7.55
.....	5.80	6.80	6.00	5.00	4.20	4.30	5.50	3.95	3.65	4.45	4.15	7.30
.....	5.60	7.00	6.00	4.90	4.50	4.30	5.30	3.95	3.85	4.40	4.25	6.90
.....	5.90	10.60	5.90	5.00	4.60	4.20	4.95	3.95	4.20	4.30	4.60	6.65
.....	5.70	9.00	5.90	5.10	5.30	4.20	4.85	3.95	4.60	5.85	4.50	6.00
.....	5.30	.....	6.70	5.10	5.20	4.10	5.55	3.90	6.30	6.55	4.40	5.75
.....	4.90	.....	6.70	6.20	5.00	4.30	5.45	3.90	6.00	6.00	4.25	5.90
.....	4.90	.....	6.70	.....	4.70	.....	5.40	3.70	.....	5.80	.....	5.60

Current-meter discharge measurements of Catskill Creek at South Cairo, N

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Oct. 10	2.58	23.3	Hollister and Schlecht.
Oct. 4	2.70	25.6	W. W. Schlecht.
Nov. 8	2.70	27.6	Do.
Aug. 19	2.70	39.6	Hollister and Place.
Sept. 23	2.74	35.6	W. W. Schlecht.
Nov. 9	2.75	42.3	Do.
July 4	2.75	60.9	Horton and Hollister.
Aug. 1	2.80	47.9	A. E. Place.
Oct. 22	2.82	54.2	W. W. Schlecht.
Sept. 7	2.92	68.8	A. E. Place.
Aug. 9	3.00	81.5	Do.
July 25	3.00	81.9	Do.
Sept. 2	3.00	87	Do.
Aug. 27	3.12	121.4	Do.
July 17	3.50	260.3	Pressey and Place.
July 20	3.60	307.5	A. E. Place.
June 13	2.69	40.6	W. W. Schlecht.
June 24	2.70	43.5	Do.
Aug. 27	2.74	39.4	H. K. Barrows.
Sept. 5	2.79	50	Do.
June 3	2.82	49.5	W. W. Schlecht.
May 23	2.83	51.1	Do.
Sept. 22	3.32	121	P. M. Churchill.
July 9	3.365	113.5	H. K. Barrows.
May 10	3.47	133	W. W. Schlecht.
Aug. 13	3.49	135	H. K. Barrows.
Nov. 7	3.80	235	F. H. Tillinghast.
Dec. 3	3.90	275	Do.
Oct. 10	3.92	242	P. M. Churchill.
Apr. 22	4.06	320.2	W. W. Schlecht.
Aug. 2	5.36	1,005	H. K. Barrows.
July 23	6.11	1,602	Do.
Apr. 11	6.86	2,312	W. W. Schlecht.
Mar. 13	8.66	5,483	Horton and Schlecht.

A measurement made February 27, 1902, with the stream obstr by ice, showed the discharge 363 second-feet, gage height 4.72. stream was frozen from bank to bank to a depth of 6 to 8 inche

t-meter discharge measurements of Esopus Creek at Kingston, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
	3.60	30.9	A. E. Place.
	3.80	64.2	Do.
	4.10	144.9	Do.
	4.32	148	Horton and Hollister.
	4.40	172.7	A. E. Place.
	4.45	126.5	W. W. Schlecht.
	4.55	167.8	Do.
	4.55	150.4	Do.
	4.60	180.2	Hollister and Place.
	4.62	165.8	W. W. Schlecht.
	4.62	188.1	Geo. B. Hollister.
	4.70	178.2	W. W. Schlecht.
	4.74	184.3	Do.
	4.75	195.4	Do.
	4.78	200.3	Do.
	4.85	259.2	A. E. Place.
	5.06	244.7	W. W. Schlecht.
	5.26	329.4	Do.
	5.46	352.2	A. E. Place.
	5.50	364.3	Do.
	5.56	380.8	W. W. Schlecht.
	5.65	396.1	A. E. Place.
	6.11	554.3	Do.
	6.26	728.6	Do.
	6.64	785.2	W. W. Schlecht.
	8.35	1,472	Do.
	11.46	1,720.8	Do.
	12.15	3,989	Do.
1902.			
	4.48	135.8	W. W. Schlecht.
	4.49	133	H. K. Barrows.
	4.94	191	Do.
	5.02	225	W. W. Schlecht.
	5.03	234.5	Do.
	5.13	268.8	H. K. Barrows.
	5.45	272	F. H. Tillinghast.
	5.81	450.4	Barrows and Schlecht.
	5.83	422	W. W. Schlecht.
	5.87	449	P. M. Churchill.

Current-meter discharge measurements of Esopus Creek, etc.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
1902.	*Feet.*	*Second-feet.*	
Nov. 11	6	416	F. H. Tillinghast.
Aug. 12	6.28	550	H. K. Barrows.
May 24	6.38	[a]274	W. W. Schlecht.
June 5	6.41	[a]272	Do.
Nov. 5	6.56	594	F. H. Tillinghast.
Apr. 23	6.94	828.3	W. W. Schlecht.
May 14	7.14	[a]508	Do.
July 30	7.65	1,155	H. K. Barrows.
July 24	8.11	1,348	Do.
Oct. 4	9.32	1,890	P. M. Churchill.
Mar. 12	9.90	2,843	Horton and Schlecht.
Apr. 30	10.28	2,813	W. W. Schlecht.
Apr. 10	13.37	5,021	Do.
Mar. 1	20.38	[b]12,620	Do.

[a] Measured at Glasgow Bridge, Glen Eyrie.
[b] Large quantities of floating ice in the stream. Surface velocities used.

The following measurements were also made during the peri ice obstruction by W. W. Schlecht:

February 20: Gage height, 5.38; discharge, 245 second-feet; partly frozen over. February 15: Gage height, 5.60; discharge second-feet; river mostly frozen over. February 7: Gage height, discharge, 530 second-feet; river partly frozen. September 29, p. m., the stream attained a flood stage, giving a reading of 25.2 the gage.

Current-meter discharge measurements of Rondout Creek at Rosendale, N.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
July 18	6.30	118.2	A. E. Place.
Aug. 6	6.40	99.4	Do.
Nov. 7	6.42	138.2	W. W. Schlecht
Sept. 24	6.45	139.6	Do.
Oct. 11	6.47	163.2	Do.
Oct. 11	6.47	201.8	G. B. Hollister.
Nov. 16	6.55	183	W. W. Schlecht.
July 6	6.55	319	Horton and Hollister.
Aug. 15	6.55	225.4	A. E. Place.
Oct. 7	6.60	217.5	W. W. Schlecht.

ent-meter discharge measurements of Rondout Creek, etc.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
	6.90	426.7	A. E. Place.
	6.94	526.4	Hollister and Place.
	7.03	509.9	W. W. Schlecht.
	7.15	644.6	A. E. Place.
	7.50	745.4	Do.
	7.56	836.1	Do.
	7.60	772	W. W. Schlecht.[a]
	7.80	1,200	A. E. Place.
	8	1,490.8	W. W. Schlecht.
	7.21	675.4	Do.
	11.95	5,353	Do.[a]
1902.			
	6.31	167	B. M. Churchill.
	6.33	141.9	H. K. Barrows.
	6.33	137.2	Do.
	6.33	145	Do.
	6.38	163	W. W. Schlecht.
	6.42	166	Do.
	6.55	283.4	F. H. Tillinghast.
	6.70	367	Do.
	6.83	382	W. W. Schlecht.
	6.855	421	Do.
	7.00	570	F. H. Tillinghast.
	7.39	838	H. K. Barrows.
	7.40	888	Do.
	8.07	1,529	W. W. Schlecht.
	17.60	13,936	Do.
	11.78	5,666	Do.

[a] Stream somewhat obstructed by shore ice.

itional measurements were made by W. W. Schlecht while the vas frozen over, as follows:

ruary 18, gage height, 7.70; discharge, 342 second-feet. The was frozen over from bank to bank and slush had collected the ice.

ruary 26, gage height, 8.13; discharge, 543 second-feet. Slush the ice made an unsatisfactory record.

ruary 26, gage height, 8.43; discharge, 684 second-feet. Ice cov- he river from bank to bank and slush had collected underneath.

The Delaware and Hudson Canal has been abandoned in New State, with the exception of the portion from High Falls feed Rondout Creek to tide water, below Eddyville. The gaging stati Rosendale is situated opposite the canal level between locks 6 a The water supply of this level is drawn entirely from Rondout C In order to determine the amount of this diversion during the se of canal navigation, usually from April 1 to December 10, a re has been kept at lock No. 6, or Creek Locks, at the lower end o Rosendale level. The record includes overflow at by-pass weir, v used for lockage, and flow through paddles in miter gates. The also a small amount of leakage in the lock walls and gates whic not been determined. The flow in the canal at lock No. 6 add the flow at the Rosendale station will give the total actual ru from Rondout Creek above Rosendale. The following tables the mean monthly and estimated daily diversion during the season of 1902. The estimated flow in the canal as recorded in is as follows:

Secon

October, 1901 .....
November 21, 1901 .....

Mean monthly diversion in second-feet to Delaware and Hudson Canal, lock near Rosendale, in 1902.

Secon

March [a] .....
April .....
May .....
June .....
July .....
August .....
September .....
October .....

Current-meter measurements of Wallkill River at New Paltz, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Nov. 9	5.04	178	W. W. Schlecht.
July 23	5.20	306	A. E. Place.
Oct. 11	6.30	340	W. W. Schlecht.
Oct. 11	6.30	355	Geo. B. Hollister.
Oct. 24	6.33	333	W. W. Schlecht.
Oct. 9	6.48	398	Do.
Nov. 16	6.50	402	Do.
July 7	7.19	824	Horton and Hollister.
July 8	7.25	842	Do.

[a] March 23 to 31, inclusive.

-meter measurements of Wallkill River at New Paltz, N. Y.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1901.			
	7.36	896	W. W. Schlecht.
	7.52	1,022	Do.
	7.73	1,076	Horton, Place, and Schlecht.
	7.85	1,038	A. E. Place.
	8.25	1,243	Do.
	8.90	1,676	Do.
	9.07	1,917	Do.
	10.00	2,729	Hollister and Place.
	10.60	2,982	A. E. Place.
	11.50	3,040	W. W. Schlecht.[a]
	13.70	3,277	Do.[a]
	14.85	7,365	A. E. Place.
1902.			
	5.70	124.3	H. K. Barrows.
	5.86	169	Do.
	5.96	209.5	Barrows and Churchill
	6.18	295	W. W. Schlecht.
	6.33	344	Do.
	6.40	381	Do.
	6.62	550	F. H. Tillinghast
	6.68	506	W. W. Schlecht.
	6.72	518	H. K. Barrows.
	6.80	626	F. H. Tillinghast.
	6.92	[b]680	W. W. Schlecht.
	7.33	288	Do.
	7.49	942	H. K. Barrows.
	7.57	[c]1,028	W. W. Schlecht
	7.78	597	Do.
	7.95	1,165	F. H. Tillinghast.
	7.98	1,150	H. K. Barrows.
	10.264	2,623	W. W. Schlecht.
	13.21	5,354	Do.
1	15.93	7,140	Do.

[a] Stream obstructed by ice causing backwater.
[b] Measured through ice 1 foot 6 inches to 2 feet 6 inches in thickness.
[c] Measured through ice 1 foot to 2 feet in thickness.

Current meter measurements of Fishkill Creek, at Glenham, Dutchess Co N. Y.

Date.	Gage height	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1901.			
July 24	3.60	60	A. E. Place.
Oct. 12	3.80	97	Geo. B. Hollister.
Nov. 11	3.85	82	W. W. Schlecht.
Aug. 15	3.85	110	A. E. Place.
Sept. 27	3.86	90	W. W. Schlecht.
July 20	3.90	135	A. E. Place.
July 8	3.92	147	Horton and Hollister.
Nov. 20	3.95	114	W. W. Schlecht.
Oct. 5	3.98	126	Do.
Oct. 15	4.05	137	Do.
Sept. 6	4.15	193	A. E. Place.
Sept. 18	4.22	229	Do.
Dec. 24	4.52	315	W. W. Schlecht.
Aug. 21	4.56	342	A. E. Place.
Aug. 30	4.60	325	Do.
Dec. 13	4.62	375	W. W. Schlecht.
Oct. 15	5.10	579	Do.
Dec. 31	7.43	2,210	Do.[a]
1902.			
Aug. 26	3.04	48.5	H. K. Barrows.
July 14	3.18	64.4	Do.
Aug. 11	3.51	115	Do.
Oct. 11	3.71	155	P. M. Churchill.
June 2	3.785	132.3	W. W. Schlecht.
July 28	3.90	200	H. K. Barrows.
June 17	4.00	212.5	W. W. Schlecht.
Nov. 8	4.00	233	F. H. Tillinghast.
Apr. 25	4.03	[b]152.4	W. W. Schlecht.
May 6	4.46	349.5	Do.
Feb. 11	4.87	[c]202.5	Do.
Oct. 30	4.97	697.7	C. C. Covert.
Apr. 12	5.30	772.6	W. W. Schlecht.
Mar. 5	5.79	1,129	Do.

[a] Surface velocity used.
[b] Probably incorrect.
[c] Ice along banks at gaging station, frozen from bank to bank 80 yards below stat 9 inches thick.

...ut-meter discharge measurements of Tenmile River at Tabor's bridge, below Dover Plains, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
16	5.27	245.4	A. E. Place.
28	4.36	70.3	W. W. Schlecht.
1	4.75	121.5	Do.
2	4.76	123.4	Do.
2	4.76	120.9	Do.
	4.88	140.1	Do.
5	5.01	187.6	Do.
7	6.54	554	Do.
9	7.19	692.8	Do.
	8.41	1,213.4	Do.
1902.			
	3.95	63	H. K. Barrows.
9	4.28	100	Do.
0	4.45	[a] 158	W. W. Schlecht
5	4.67	179	Do.
	4.69	184.8	H. K. Barrows.
3	4.80	211.5	F. H. Tillinghast.
4	4.87	211	Do.
6	4.88	230	W. W. Schlecht.
0	4.92	249	Do.
1	5.50	380	Do.
	5.80	443	P. M. Churchill.
6	6.13	526	W. W. Schlecht.
	6.18	558	Do.
	6.46	640	Do.
	7.18	821	H. K. Barrows.
	10.41	2,386	W. W. Schlecht.

[a] River nearly covered with ice from bank to bank and 1½ to 2½ inches thick.

Current-meter discharge measurements of Housatonic River at Gaylordsvill

Date.	Gage height.	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1900.			
Oct. 20	3	303	E. G. Paul.
Oct. 24	3.10	370	Do.
Aug. 10	3.25	422	Do.
Aug. 9	3.30	450	Do.
1901.			
Aug. 3	3.50	549.5	A. E. Place.
Sept. 28	3.78	700.8	W. W. Schlecht.
Sept. 13	4	911.7	A. E. Place.
Oct. 29	4.05	951	W. W. Schlecht.
Nov. 23	4.11	965.4	Do.
Nov. 13	4.82	1,863.7	Do.
Dec. 28	5.16	2,250	Do.
1902.			
Sept. 8	3.45	543	H. K. Barrows.
Sept. 19	3.75	640	Barrows and Churchi
Aug. 20	3.95	835	H. K. Barrows.
Aug. 5	4.28	983	Do.
July 11	4.30	1,159	Do.
Nov. 29	4.40	1,281	F. H. Tillinghast.
June 23	4.46	1,177	W. W. Schlecht.
Nov. 15	4.50	1,356	F. H. Tillinghast.
Oct. 3	5.35	2,133	P. M. Churchill.
May 3	6.10	4,459	W. W. Schlecht.
July 22	6.68	5,119	H. K. Barrows.
Mar. 18	7.63	8,259	W. W. Schlecht.
Mar. 4	9.9	13,601	Do.

INDEX.

Page.

Abbott, H. L., and Humphreys, A. A., cited on form of vertical velocity curve 22
reference to 20, 46
Alkalinity, method of determining 76
of streams discussed, diagram showing 76
table showing 77–85
Allen, C. J., work of 62
Austin, Tex., hydraulic plant at, failure of 10
Babb, C. C., reference to 20
Bear Valley dam, California, lack of water in 11
Birdsall, G. N., measurements suggested by 13
Catskill Creek, alkalinity observations on, diagram showing results of 76
color observations on, diagram showing results of 74
discharge measurements of 96
gage heights of 87
gaging station on, description of 27–28
view of 26
hardness observations on, diagram showing results of 78
quality of water of, table showing 77
turbidity observations on, diagram showing results of 70
velocities in vertical sections on, tables showing 33–40, 45
under ice, tables showing 58
velocity at mid depth and mean velocity on, relation between 46
vertical velocity curve for, diagram showing 24
Color, methods of determining 73–76
of streams discussed, results of observations of, diagram showing 74
table showing 77–85
standards for determining 74–75
tubes and disks for determining plate showing 72
Cunningham, Allan, cited on velocity of rod floats 18
Current meter, plate showing 20
use of, in determining velocity 19–20
view showing 18
Dams, use of, in determining velocity 18–19
Darcy, H., formula derived by 26
De Prony, work of 26

Page.

Discharge measurements, methods of making, views of 18
tables of 96–104
Disks for measuring color of river water 72
Dover Plains, gaging station at, description of 29
Tenmile River at, discharge measurements of 103
gage heights of 92–93
velocities in vertical sections on, tables showing 43, 45
Ellis, T. G., reference to 20, 46
Esopus Creek, alkalinity observations on, diagram showing results of 76
color observations on, diagram showing results of 74
curves of equal velocity on, diagram showing 22
discharge measurements of 97–98
gage heights of 88
gaging station on, description of 28
view of 26
hardness observations on, diagram showing results of 78
quality of water of, table showing 81–81
turbidity observations on, diagram showing result of 70
velocities in vertical sections on, tables showing 32–34, 45
under ice, table showing 54–55, 63, 64
velocity at mid depth and mean velocity on, relation between 46
vertical velocity curve for, diagram showing 24
under ice cover, diagram showing 61
Fishkill Creek, alkalinity observations on, diagram showing results of 76
color observations on, diagram showing results of 74
discharge measurements of 102
gage heights of 91–92
gaging station on, description of 28
hardness observations on, diagram showing results of 78
quality of water of, table showing 82–84
turbidity observations on, diagram showing result of 70

Page.

Fishkill Creek, velocities in vertical sections on, tables showing... 41-42, 45
velocity at mid depth and mean velocity on, relation between.... 46
vertical velocity curve for, diagram showing 24
Floats, methods of using, to determine velocity 15-18
Flow, estimates of, variation in 12
Francis, J. B., cited on velocity of rod floats..... 17
formula for determining velocity by. 18
reference to 19
Freeman, J. R., reference to..... 19
Fteley, A., and Stearns, F. P., reference to. 19
Gage heights, tables showing..... 87-95
Gaging stations, views of..... 26, 28
Gaylordsville, Conn., gaging station at, description of 29
gaging station at, view of..... 28
Housatonic River at, discharge measurements of..... 104
gage heights of..... 93-95
velocities in vertical sections on, tables showing..... 44
Gila Bend, Ariz., failure of dam at..... 11
Glenham, gaging station at, description of..... 28
Fishkill Creek at, discharge measurements of 102
gage heights of..... 91-92
velocities in vertical sections on, tables showing 41-42, 45
Gordon, R., work of..... 26
Hardness, method of determining..... 76-77
of streams discussed, diagrams showing 78
tables showing 77-85
Hazen, Allen, method of determining color devised by..... 73
Horizontal velocity curves on Wallkill River, diagram showing 30
Housatonic River, alkalinity observations on, diagram showing results of..... 76
color observations on, diagram showing results of 74
discharge measurements of..... 104
gage heights of 93-95
gaging station on, description of..... 29
view of..... 28
hardness observations on, diagram showing results of..... 78
quality of water of, table showing 84-85
turbidity observations on, diagram showing results of..... 70
velocities in vertical sections on, tables showing 44
velocity at mid depth and mean velocity on, relation between.... 46
vertical velocity curve for, diagram showing..... 24
Humphreys, A. A., and Abbott, H. L., cited on form of vertical velocity curve..... 22
reference to..... 20, 46

Page.

Ice, broken and tilted, flow of rivers under .....
smooth and unbroken, flow of rivers under 48
Jackson, D. D., and Whipple, G. C., reference to 71
Jellys Ferry, Cal., Sacramento River at, relation of mean and surface velocity on.....
Kingston, gaging station at, description of.....
gaging station at, view of.....
Esopus Creek at, curves of equal velocity on, diagram showing...
discharge measurements of..... 97
gage heights of .....
velocities in vertical sections on, table showing..... 32-34,
Lagrange, Cal., Tuolumne River at, relation of mean and surface velocity on .....
Lippincott, J. B., quoted on velocity curves on rivers in southern California.....
Measurements, method of making, views of.....
Meter. *See* Current meter.
Mississippi River, vertical velocity curve on, form of..... 22
Murphy, E. C., reference to .....
New Paltz, gaging station at, description of.....
gaging station at, view of.....
Wallkill River at, curves of equal velocity on, diagram showing...
discharge measurements of..... 100-1
gage heights of 90
horizontal velocity curves on, diagram showing .....
ice cover and curves of equal velocity on, diagram showing...
velocities in vertical sections on, tables showing..... 37-38
New York City, gaging stations near ....
water supply of, proposed sources of.. 12
Newell, F. H., letter of transmittal by...
Place, A. E., work in charge of.....
Platinum-cobalt method of measuring color, description of..... 7
Platinum-wire process for determining turbidity, method of application of..... 6
Powell, A. O., work of.....
Price electric current meter, plate showing .....
Quality of river water, discussion of..... 6
Rafter, G. W., reference to.....
River channels, velocity in, methods of measuring 1
Rod floats, method of using, to determine velocity 1
Rondout Creek, alkalinity observations on, diagram showing results of.
color observations on, diagram showing results of .....
discharge measurements of..... 98

Page.

Rondout Creek, gage heights of 89
gaging station on, view and description of 28
hardness observations on, diagram showing results of 78
quality of water of, table showing 78-80
turbidity observations on, diagram showing results of 70
velocities in vertical sections on, tables showing 35-36, 45
under ice, tables showing ... 56-57, 63, 64
under ice broken and tilted, tables showing 66, 67
velocity at mid depth and mean velocity on, relation between ... 46
vertical velocity curve for, diagram showing 24
under ice cover, diagram showing 61
Rosendale, gaging station at, view and description of 28
Rondout Creek at, discharge measurements of 98-100
gage heights of 89
velocities in vertical sections on, tables showing 35-36, 45
Rough bed, effect of, on velocities in vertical sections 46-47
Sacramento River, California, relation of mean and surface velocity on. 23
San Gabriel River, California, relation of mean and surface velocity on. 24
Santa Ana River, California, relation of surface and mean velocity on. 24
Schlecht, W. W., work in charge of 27
Smooth bed, effect of, on velocities in vertical sections 46-47
South Cairo, Catskill Creek at, discharge measurements of 96
Catskill Creek at, gage heights of 87
velocities in vertical sections on, tables showing 39-40, 45
gaging station at, description of 27-28
view of 26
Stearns, F. P., cited on surface velocity .. 21
Stearns, F. P., and Fteley, A., reference to 19
Subsurface floats, method of using, to determine velocity 16-17
Surface floats, methods of using, to determine velocity 15-16
Sweetwater reservoir, California, lack of water in 10
Tenmile River, alkalinity observations on, diagram showing results of 76
color observations on, diagram showing results of 74
discharge measurements of 103
gage heights of 92-93
gaging station on, description of 29
hardness observations on, diagram showing results of 78
quality of water of, table showing ... 82
turbidity observations on, diagram showing results of 70

Page.

Tenmile River, velocities in vertical sections on, tables showing 43, 45
velocity at mid depth and mean velocity on, relation between . 46
vertical velocity curve for, diagram showing 24
Tube floats, methods of using to determine velocity 17-18
Tubes for determining color, method of filling and holding 75
plate showing 72
Tuolumne River, California, relation of mean and surface velocity on . 23
Turbid water, color of, method of determining 75
Turbidity, determination of 68-73
of streams discussed, diagram showing result of 70
tables showing 77-85
platinum-wire process for determining, method of application of . 69-73
standard of 69
stick for determining, view of 86
Velocities in vertical sections, tables showing 32-47
Velocity in river channels, methods of measuring 14-20
point of mean depth from surface to. 20-21
relation of mean to mid depth 46
to surface 23-26
Velocity curves, horizontal, on Wallkill River, diagram showing 30
Velocity curves, vertical, description of, on streams without ice cover. 20-47
diagram showing 24
form of 22-23
Vernon-Harcourt, L. F., cited on relation of mean to vertical velocity .. 26
Vertical sections, velocities in, tables showing 32-47
Vertical velocity, relation of mean to surface 23-26
Vertical velocity curves, description of, on streams without ice cover. 20-47
diagram showing 24
form of 22-23
stations for obtaining 27-29
Wallkill River, alkalinity observations on, diagram showing results of 76
color observations on, diagram showing results of 74
discharge measurements of 100-101
equal velocity curves on, diagram showing 30
gage heights of 90-91
gaging station on, description of ... 28
view of 26
hardness observations on, diagram showing results of 78
horizontal velocity curves on, diagram showing 30
ice cover and curves of equal velocity on, diagram showing 48
quality of water of, table showing ... 81-82

Page.
Wallkill River, turbidity observations on, diagram showing results of... 70
velocities in vertical sections on, tables showing 37-38, 45
under ice, tables showing... 50-53, 63, 64
under ice, broken and tilted, tables showing..... 65, 67
velocity at mid depth and mean velocity on, relation between.... 46
vertical velocity curve for, diagram showing..... 24
Wallkill River, vertical velocity curve for, with ice cover, diagram showing..... 60
Warm Springs, Cal., Santa Ana River at, relation of surface and mean velocity on..... 9
Water powers, value and utilization of.. 9
Weirs, use of, in determining velocity .. 18
Whipple, G. C., color disks rated by 71
Whipple, G. C., and Jackson, D. D., reference to 71

O

Water-Supply and Irrigation Paper No. 77 Series O, Underground Waters, 19

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE

WATER RESOURCES OF MOLOKAI

HAWAIIAN ISLANDS

BY

WALDEMAR LINDGREN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

CONTENTS.

	Page.
Letter of transmittal	7
Introduction	9
Topography	9
Geology	12
Coral reefs	15
Climate	16
Soils	18
Vegetation	20
Causes of decrease of forest area	23
Fauna	24
Culture	24
Water supply	26
General principles	26
Springs	28
Springs on sea shore	28
High-level springs	29
Running streams	30
Streams of the north coast	30
Waihanau	31
Waialeia	31
Waikolu	31
Pelekunu	32
Wailau	32
Halawa	32
Streams of the south coast	33
Meyers Gulch	33
Kaunakakai Gulch	35
Onini Gulch	36
Kawela Gulch	36
Kamalo Gulch	37
Wells	37
Kaluakoi	37
Palaau	38
Well No. 1	38
Well No. 2	38
Well No. 3	38
Palaau deep well	39
Well in Meyers Gulch	39
Well at mouth of Meyers Gulch	39
Naiwa	39
Kalamaula	39
Cocoanut grove deep well	39
Cocoanut grove shallow well	40
Cocoanut grove *pits*	40

Water supply—Continued. Pa
Wells—Continued.
Kaunakakai
Cane field wells
The settlement well
The 3 upper wells
The deep well
The 12 wells for main pumping station
Risdon wells
Kawela
Well No. 1
Well No. 2
Well No. 3
Well No. 4
Well No. 5
Well No. 6
Well No. 7
Well No. 8
Well No. 9
Other wells
Theoretical amount of water available
Utilization of the water supply
Utilization of the running streams
Waikolu
Kawela
Makakupaia
Kamiloloa
Luahine Fork
Waialia
Waihanau
Kahapakai
Wailau and Pelekunu
Utilization of the ground water
Palaau
Cocoanut grove wells
Kaunakakai
Risdon wells
Kawela
Recapitulation
Electric power available

ILLUSTRATIONS.

		Page.
PLATE I.	Map of Molokai	9
II.	*A*, South coast of Molokai at Kolo windmill, west end of island (looking west), showing sea cliff and successive basalt flows sloping down toward the coast; *B*, Mouth of Kawela Gulch, south coast of Molokai, showing bowlder-filled creek bed and steep side slopes cut in basalt	10
III.	*A*, Kamalo Gulch, south coast of Molokai, showing parts of surface of volcanic cone, deeply dissected by steep gulches, débris fans at mouth of gulches, and coral reef below shallow water near shore; *B*, North coast of Molokai (looking west from the landing at Wailau), showing fault scarp along northern coast, horizontal basalt flows near base of cliff, and peninsula of leper settlement in the distance	12
IV.	*A*, North coast of Molokai (looking west from summit of trail to leper settlement), showing summit plateau and fault scarp exposing a great number of basalt flows, elevation 1,600 feet above sea level; *B*, North coast of Molokai, mouth of Wailau Valley (looking east), showing fault scarp 3,000 feet high and alcove type of eroded valleys	14

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., October 1, 1902.

SIR: I have the honor to transmit herewith a manuscript by Waldemar Lindgren, geologist of this Survey, with the request that it be published in the series of Water-Supply and Irrigation Papers. This manuscript relates to the water supply of Molokai, one of the Hawaiian Islands. It was prepared from the results of an investigation made unofficially by Mr. Lindgren in 1900. The observations made at that time and the conclusions drawn from them have such general interest, as showing the possibilities and limitations of one of the group of islands, that it is desirable to make them available to the public. Of especial interest are Mr. Lindgren's notes on the gradual decrease of the forested area, the probable effect of grazing, and the intimate relations of these to the available water supply.

The problems of water conservation are here shown to be rather difficult and involved, but are similar in many respects to those of the arid West, the solution being found in combined systems of storage, water-power development, use of the power in pumping, the construction of wells, collecting tunnels, and the economical employment of various devices for lifting water. Opportunity is thus offered for the exercise of skill and mature judgment by the geologist, hydrographer, and civil and mechanical engineer.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director of United States Geological Survey.

50′
45′
Lepau
Kaaemilo
Kihipua
Papala
Waaepuka
Kiekie
Puahaunui
Lamalomo
Kapuupoi
Kalanikaula
Kekahi
Kabei
Kua
Puuloa
Kanaha
Keonepoko
Kealua
Lupehu
Kalaekapu
Hano
Pahau
Walalua
Honomuni
Honomuni Har.
Kupeko
Pukoo Har.
Mapulehu
Mahilikua
Pauwalu Har.
Old Fish Pond
Fish Pond
Kaluauna
Pukaa
Naehu
Keahialulu
Halawa
Moanui
Homuli
Puu Onola
Puu Mano
Waaiua
Kaiwaiu
Kaiwaiu Pt.
Kaiwaiu Bay
Kaiwaiu Gulch
Kaiwaiu Ridge
Kaiwaiu Valley
Kaiwaiu Flat
Kaiwaiu Pali
Kaiwaiu Stream
Kaiwaiu Trail
Kaiwaiu Road
Kaiwaiu Spring
Kaiwaiu Well
Kaiwaiu Cave
Kaiwaiu Heiau
Kaiwaiu Burial
Kaiwaiu Petroglyph
Kaiwaiu Lookout
Kaiwaiu Overlook
Kaiwaiu Summit
Kaiwaiu Saddle
Kaiwaiu Ridge
Kaiwaiu Valley
Kaiwaiu Flat
Kaiwaiu Pali
Kaiwaiu Stream
Kaiwaiu Trail
Kaiwaiu Road
Kaiwaiu Spring
Kaiwaiu Well
Kaiwaiu Cave
Kaiwaiu Heiau
Kaiwaiu Burial
Kaiwaiu Petroglyph
Kaiwaiu Lookout
Kaiwaiu Overlook
Kaiwaiu Summit
Kaiwaiu Saddle

THE WATER RESOURCES OF MOLOKAI, HAWAIIAN ISLANDS.

By WALDEMAR LINDGREN.

INTRODUCTION.

Molokai is the fifth in size of the Hawaiian Islands, and is situated between Oahu and Maui. Oahu is 23 miles distant, and from higher points Diamond Head is in plain sight on clear days. From Maui it is divided by a sound only 8 miles wide. Not much farther to the south rises the dry, rocky coast of Lanai, a still smaller island, chiefly used as a sheep range. Molokai is a narrow strip of land, extending 39 miles from east to west and having an average width of a little less than 7 miles. The area is 261 square miles. The population in 1900 numbered 2,500. The island stands on the submarine plateau from which the whole northern group rises, so that no extreme depths are found in the channel between Oahu and Molokai, nor between Molokai and Maui. Coral reefs fringe nearly the whole south coast of Molokai, but few occur on the north shore. This north shore is the windward side, receiving the full impact of the trade winds and a great amount of moisture. In strong contrast to this the south shore is extremely dry.

Molokai is outside of the ordinary course of travel. No description of the island has ever been published, as far as I know, excepting somewhat stereotyped references to the leper settlement in books of travel. The more easily accessible portions are not attractive, and the northeast coast, which is characterized by wonderful scenery, is rarely ever visited by travelers.

TOPOGRAPHY.[a]

Three natural divisions may be recognized in the relief of the land: (1) The west end, or Kaluakoi; (2) the low gap separating Kaluakoi from the principal mountain range; and (3) the eastern range.

[a] The Hawaiians do not ordinarily designate directions by the four points of the compass. They have instead two very expressive terms: *Mauka*, meaning upward, toward the higher parts of the island, and *Makai*, meaning the opposite, or toward the sea. It also seems that they do not usually designate the water courses by special names, but instead apply to them the name of the subdivision of land through which they happen to flow. As will be seen from the map, each subdivision has its own name.

The west end, or Kaluakoi, comprises about 55 square miles. This area consists of a broad, bare, and grassy ridge, beginning at the light-house at the southwestern extremity of the island and culminating, with an elevation of 1,382 feet, in the round-topped hill of Mauna Loa. Rocky and abrupt ravines lead southward from this backbone to the sea, while long gulches with gentler grade, and separated by broad ridges, reach the north shore. Here a steep cliff has been formed by the action of the waves (Pl. II, *A*). A sharp slope, or pali, a few hundred feet high, runs northward from Mauna Loa, dividing the west end from the low gap.

A low gap separates Kaluakoi from the principal mountain range of the island. The lowest point of this divide is 450 feet above sea level. Gently rolling smooth surfaces characterize this broad gap or saddle; on the south it is cut by shallow gulches and slopes gradually to the sea, while on the north shore the surf has sculptured a low sea cliff gradually merging into the great precipice or pali which from here on follows the northern coast. This gap contains the best and most extensive sugar-cane lands on the island, the total area being about 14,000 acres of deep red, extremely fertile soil. This area is sharply separated from the west end by Mauna Loa Creek on the south side of the island and by the above-mentioned low pali on the north. Eastward the rolling country gradually rises to the plateau of the main mountains of the island.

The eastern range comprises the largest part of the island. This may be briefly described as a segment of a circle, the chord of which extends east and west and has a length of about 25 miles. The line dividing the north-south drainage is, roughly speaking, parallel to the curve of the southern coast. The mountains culminate almost in the center of the island in the peak of Kamakou, which attains an elevation of nearly 5,000 feet. The south slope is gradual, and is furrowed by a great number of straight and narrow, though often deep, ravines (Pl. II, *B*, and Pl. III, *A*). The north slope is abrupt, in places precipitous, and is marked by five most extraordinary recesses or alcoves, cut in the face of the scarp. This great precipice and these alcoves are the most remarkable feature of the island's topography. North of the great gap of the island the great pali has a height of only a few hundred feet, which increases to 900 feet north of Molokai Home ranch and reaches 1,500 feet, where the trail to the leper settlement crosses it. From this point eastward the great precipice is much higher and from Waikolu to Wailau attains elevations of from 2,500 to 3,500 feet; then it gradually decreases again to Halawa, where it ends near the eastern point of the island, having there an elevation of 850 feet. The character of this pali may be seen from Pl. III, *B*, and IV, *A*. When of moderate height, i. e., up to 1,500 feet, it forms practically one continuous slope of from 50° to 70°, with practically no level land below. The surf beats directly against the foot of the escarpment.

OUTH COAST OF MOLOKAI AT KOLO WINDMILL, WEST END OF ISLAND, LOOKING WEST.

Showing seacliff and successive basalt flows sloping down toward the coast.

B. MOUTH OF KAWELA GULCH, SOUTH COAST OF MOLOKAI.

Showing bowlder-filled creek bed and steep side slopes cut in basalt.

At the mouth of the Wailau Valley, and wherever it attains great height, there is usually a vertical or practically vertical cliff from a few hundred to a thousand feet high. Above this a slightly more gradual slope prevails, but for 2,000 feet above sea level the average declivity is often about 70°. Above this the slope flattens to something like 45°. The precipitous rock walls are channeled by a great number of parallel grooves cut by the rain water, and wherever the slopes are not vertical the dark colored rock is covered by a mantle of bright green vegetation. Only in one place is there is any important land mass projecting northward at the foot of the pali. That is the peninsula of the leper settlement, Kalaupapa, a rocky and dry peninsula 2 miles wide and 2 miles long, its highest point rising only a few hundred feet above the sea and marked by the crater of a small extinct volcano.

Next to the great pali itself the most remarkable features of the northern coast are the deep recesses or alcoves which erosion has carved into it, alcoves with exceedingly steep, sometimes perpendicular slopes, of wonderful beauty and grandeur, over the edges of which the waters of the upper drainage basins fall in numberless cascades, increasing to magnificent waterfalls during the rainy season.

West of Waikolu Valley the main divide of the island is close to the northern shore, but here it turns southeasterly and curving follows approximately the central line of the island. The three western alcoves, Waihanau, Waialeia, and Waikolu, have as yet not cut back very far and are therefore most characteristic of their type. All three have a shorter upper high level drainage consisting of small canyons in the high plateau, 200 to 400 feet deep, connected by cascades with the lower straight and deep canyons, 2 to 3 miles in length. The even verdure-clad side slopes descend at angles of from 40° to 60° to the water course in the bottom. At the head of the canyon the declivities become much more precipitous and form an amphitheater in strong contrast to the rolling or level summit plateau. At the head of the alcove and at various places from its sides the waterfalls descend like narrow white threads for 2,000 feet into the black depths of the chasm. Deep grooves and holes have been worn into the rock by the falls, so that in places they disappear altogether from view. More extensive and branching are the two principal streams of the island, Pelekunu and Wailau. They occupy watersheds of 4 or 5 square miles, but they, too, are surrounded by the same precipices, especially near the headwaters at the main divide. They are clearly of the same origin as the smaller alcoves, but a stronger erosive action has widened the valleys and extended their canyons. The grades of the streams are heavy throughout, and except at the north of the canyon there are practically no bottom lands. Pl. IV, *B*, shows the mouth of Wailau, with the broad, almost U-shaped form at the debouchure, and the furrowed slopes descending from the high plateau of the island.

The Halawa, another of the permanent streams of the island, flows in an easterly direction, heading in the swamps of the plateau east of Wailau, descending in a great waterfall to the lower alcove or canyon, and debouching near the extreme eastern end of the island.

From the headwaters of Waihanau to Kamakou, the highest peak on the islands, the summit region consists of gently sloping or hilly plateaus, generally swampy and cut by sharply incised ravines. The elevation of this plateau is only 2,000 feet south of the leper settlement but increases to 3,500 south of Waikolu and to over 4,000 between Waikolu and Pelekunu. Parts of the plateau project between the canyons, contrasting sharply against the precipices of alcoves and pali. From Kamakou for several miles eastward there is no central plateau, or only fragments of it. The drainage from north and south has cut in deeper and left only a sharp and jagged ridge. But between Wailau and Halawa there are again several square miles of the upper surface left.

The south slope of the island is very different from the northern. South of the divide the plateau gradually changes to a sharper slope, over which the water courses find their way in small cascades and falls. This decided slope is most accentuated on the Kawela, but is noticeable all along the south side of the island. The lower declivities, up to an elevation of 800 feet above the sea, are again gentle, having an inclination of from 5° to 8°, and a fringe of narrow flats follows the coast line. Instead of a few great canyons, some forty or fifty gulches and ravines form the drainage ways of the southern slope. All of these have the same characteristics, namely, a straight course, small drainage area, sharp grades, especially in their middle portion, and very abruptly incised sides, rarely, however, cut more than 400 or 500 feet below the slope of the surface. These conditions are the natural result of a comparatively recently established drainage system over the smooth sides of a volcanic cone. East from Kawela the straight, steep gulches are even more numerous than in the western part. Pl. III, *A*, shows the great Kamalo Gulch back of the plantation of the same name. It illustrates well the V-shaped form of the canyons as well as the partially preserved surface of the old lava cone. On the whole, the streams draining north are permanent, while those draining south carry water only during the rainy season, and then intermittently.

GEOLOGY.

Like the other islands of the Hawaiian group, Molokai is almost entirely of igneous origin. It is a volcanic cone built up in the middle of the ocean by a great number of superimposed basaltic flows. The island is, in fact, like Maui, formed by two volcanoes, and these two cones are separated by a low gap on which secular disintegration has reduced the basalt to a deep red soil.

A. KAMALO GULCH, SOUTH COAST OF MOLOKAI.

Showing parts of surface of volcanic cone deeply dissected by gulches, débris fans at mouth of gulches, and coral reef below shallow water near shore.

B NORTH COAST OF MOLOKAI, LOOKING WEST FROM THE LANDING AT WAILAU.

Showing fault scarp along northern coast, horizontal basalt flows near base of cliff, and peninsula of leper settlement in the distance.

The west end forms one, separate and complete, though comparatively low cone. Partly obliterated craters are still visible near the summit, between Mauna Loa, Kaana, and Amikopala. The cone is not very regular, and secondary centers of eruption were probably located near the southwest and northwest corners of the island. The steep pali running north from Mauna Loa to the coast indicates a dislocation along which the east side has dropped a few hundred feet.

The main or eastern part of the island is not of so simple a structure. It represents one part, and probably the smaller part, of a large volcano, the northern part having dropped down along a great break or dislocation to a depth of from a few hundred to 3,000 or even 4,000 feet. Thus, the great northern pali, described in the previous pages, is really a break or a fault line, which split the volcano in two. The evidence of this is clear and convincing. The slopes of the lava flows are everywhere to the south, from 4° to 13°; even in the cliffs on the north coast the same inclination is observed. This, in conjunction with the form of the island, shows that a part of the volcano has been removed. Neither wave action nor erosion by running water could possibly have produced such an escarpment as that of the great pali, reaching 3,000 feet in height. The work of erosion on this cliff is shown plainly enough in the great alcoves cut by the water courses and described in previous pages. This erosion is still cutting southward and the divide is no doubt steadily migrating in that direction.

Dana, I believe, was the first to insist that the outlines of these islands have been to some degree determined by dislocations; and in his "Characteristics of Volcanoes"[a] is the only reference to Molokai which I have found in geological literature. It is as follows:

> Molokai was once, as its lava streams prove, a doublet of volcanoes like Maui, but it has been shaved down to a strip of land. The eastern part has an alcoved precipice facing the north, which rises to a height of 2,500 feet above the sea. Thus, such precipices are rather the rule in the Hawaiian group, and if seashore erosion is not the origin, fractures and subsidence must be.

Dana's view of the causes of the abrupt topography on the eastern coast of Oahu has been disputed by C. H. Hitchcock,[b] who believes that the action of erosion is sufficient to account for it. There is no doubt that deep canyons with very steep walls and almost perpendicular precipices near the heads of the water courses are most characteristic among the forms of erosion on the windward side of the island, and that, therefore, some caution must be exercised in discriminating precipices of erosion from those of fault scarps. However, in the case of Molokai, Dana's statement is undoubtedly true; the great pali is most certainly a fault scarp of magnificent size.

The low peninsula of Kalaupapa, the only land of importance at the foot of the cliff, seems to be a part of this sunken area, still above

[a] 1890, p. 290. [b] Bull. Geol. Soc. Am., Vol. II, 1899, p. 23.

water. A crater and several lava streams still remain on this peninsula and are better preserved than most of those on the south side. The gently sloping summit plateau does not contain, as far as known any remaining craters, but it is covered by extremely thick vegetation and few parts of it are accessible. Numerous smaller subcraters or parasitic cones remain, imperfectly preserved, on the long southern slope of the island. They generally have flat tops—the crater funnels being filled in—and intense red or yellow colors due to thermal action on the lavas. Such are Middle Hill, Puu, Luahine, Kakaloha, Manini-bolo, and many others.

Similar in general to the other islands, the rocks of Molokai consist almost exclusively of dark basaltic, fine-grained lavas of more or less porous structure. The flows are thin, and range from a few feet up to 50 feet in thickness, but rarely exceed the latter limit. Laterally the flows are ordinarily not continuous over a great distance, hence outcrops or wells only a few hundred feet apart may show very different sections. Harder, more compact lavas alternate with exceedingly porous, loose breccias or agglomerates. The deepest parts of the gulches, the well sections, and the palis at Waikolu, Pelekunu, and Wailau all show the same structure, clearly indicating that the island has been built up by rapidly succeeding thin lava flows. The probability is very strong that this same structure and the same kinds of rock continue down to a depth of several thousand feet. No petrographic study of the rocks has been undertaken, but a few thin sections make it evident that the rocks chiefly consist of normal feldspar basalt, somewhat glassy, and with olivine, occasionally also containing phenocrysts of soda-lime feldspars. Thus far the only kinds of rocks recognized by petrographers in the Hawaiian Islands are of the type of feldspar basalts, with occasional occurrences of nepheline-basalts or nepheline-melilite-basalts. In exploring the headwaters of Wailau in the very heart of the dissected volcano of Molokai, however, an interesting occurrence of coarse-grained intrusive rock was found. Crossing the gap north of Mapulehu one descends over a precipice leading down to the valley of Wailau over a difficult and almost dangerous trail, which finally follows the bed of the east fork down to its junction with the larger west fork. Down to the junction only ordinary basaltic rocks are met with, but the west fork is full of heavy bowlders of a dark-green, coarse, granular rock, manifestly different from anything formerly described from the islands. The rock was not found in place, nor was the west fork followed up to its source, where these bowlders must come from. Indeed, in the thick tropical jungle which covers the whole watershed of Wailau, this is a very serious undertaking, but there must be a large mass of this rock in place, too large to have been carried up by the eruption of the lavas, and therefore it is most probably an intrusive body injected into the volcanic masses and there consolidated.

NORTH COAST OF MOLOKAI LOOKING WEST FROM SUMMIT OF TRAIL TO LEPER SETTLEMENT.

g summit plateau and fault scarp, exposing a great number of basalt flows. Elevation 1,600 feet above sea level.

NORTH COAST OF MOLOKAI, MOUTH OF WAILAU VALLEY, LOOKING EAST.

Showing fault scarp 3,000 feet high and alcove type of eroded valleys.

Upon examination in thin section the rock presents a normal coarse granular structure, without glass, and consists of broad laminæ of a soda-lime feldspar not far from anorthite. Between these lie grains of a pale-violet, slightly pleochroic augite, with which are associated numerous grains of an iron ore. In addition, there are grains of olivine, slightly serpentinized, and in much smaller quantity than the augite. The rock is therefore a very coarse olivine-diabase.

Mr. Monroe, the superintendent of Molokai ranch, gave me a small specimen of a somewhat similar but slightly more decomposed rock which he had broken from a large bowlder in one of the principal streams on Kauai, the most northerly of the large Hawaiian islands. This proved to be very similar to the rock just described, being a coarse-grained diabase. A remarkable feature of the rock from Kauai is the deep purplish color of the augite. It is only slightly pleochroic.

These two coarse-grained rocks are the only occurrences of the kind thus far found in the Hawaiian Islands.

Unlike Oahu, Molokai has no extensive flats of sediment soil underlain by coral and tuffs. The sediments are chiefly confined to small strips and areas of less than 200 acres, and occur at intervals, especially near the mouths of the gulches along the south coast from Palaau to Pukoo. The soil is ordinarily, at no great depth, underlain by basaltic lava. Rarely is there a thin layer of coral rock between the soil and the lava rock.

The gap or the space between the two volcanoes which make up the island is of a rolling character and is covered by soil. A considerable part of this gap is covered by sediment soil, fine red soil, and well-rolled gravel, mixed. This sediment is doubtless chiefly carried down from the east side, and antedates the time when the volcano was split in two and the northern half engulfed in the sea.

As may be expected, the extremely steep gulches from Kawela eastward have brought down big fields of bowlders from the slopes above (Pl. II, *B*).

CORAL REEFS.

A coral reef from one-half to 1 mile wide fringes practically the whole southern coast of the island. The parts adjacent to the main gulches are gradually being filled up by mud. Thus, the island is gradually growing out in this direction. Seen from a high point, the reddish mud flats skirting the shore contrast strongly against the brilliant emerald green of the reef; and beyond this is the dark violet-blue color of the deep sea.

Small amounts of coral rock, indicating a former higher water level, are found all along the southern coast; usually these only reach 25 feet above water level, though in one place—near Puu Manibolo—

this old coral reef extends up to 130 feet above the sea. The submergence was evidently of short duration.

The coral sand carried up by the waves forms a very narrow fringe all along the southern coast. A large dune wall of coral sand, about 12 feet high, skirts the western coast at Papohaku flats.

Though the coral reefs on the northern or windward side are not extensive, a very large area of dune sand occurs north of the gap and extends for several miles westward, having a width as great as 4,000 feet. The locality is particularly exposed to the full force of the trade winds, and the sand is carried up to the top of a 500-foot hill, where it accumulates in dunes which reach a thickness of 20 feet. Westward the sands finally reach the two creeks emptying near Papohaku, from which repositories the winter floods carry them down to the sea. Part of these dunes are consolidated to hard sandstones. In some of these are seen peculiar footprints which are similar to, and yet somewhat different from, the imprint of a human foot. There are also many obviously recent inscriptions, etc., and, as the Hawaiians are not altogether averse to a practical joke, the real character of these footprints may as yet be left an open question.

CLIMATE.

In regard to temperature, the island possesses the same equable climate as that enjoyed by the others of the same group; frost probably never occurs, even at the highest elevations. The trade winds are strong, especially during the winter months and on the northern coast. During long periods it is impossible to effect a landing at the settlements of Wailau and Pelekunu. Even along the south coast the winds are usually strong in the afternoon, and over the bare west end, or Kaluakoi, and over the gap the breezes sweep without hindrance. There is in general a wet season, extending from October until the end of May, and a dry season including the summer months. On the whole, the west end, the gap, and the south shore as far as Kamalo are included in the arid zone of the island, while the whole northeasterly part may be counted as one of abundant precipitation. All points over 2,500 feet in elevation receive an abundant rainfall. Most of this falls in the winter, but showers occur at intervals all through the summer. Accurate data regarding rainfall extending over any considerable period are not obtainable.

Data collected by Dr. Morritz at Mapulehu, on the southern coast and the eastern part of the island, from 1894 to July, 1899, show an average annual precipitation of 34 inches with but little variation and no apparent decrease. The maximum precipitation is usually in December, with as much as 6 inches, while the minimum monthly precipitation in the summer is 1 inch.

At Kaunakakai no records have been kept except for a month or

two in 1900, but it is apparent that the rainfall decreases rapidly west of Mapulehu. The probable annual rainfall at Kaunakakai does not exceed 10 inches, thus indicating a very dry climate. About 2 inches are said to have fallen in January, 1900. About 0.6 of an inch fell April 24, 1900, while since that time, up to July 1, 1900, there were only slight showers at great intervals; a little rain fell June 23, and again a little on June 27 and 28.

There are indications that the rainfall at Palaau, on the south side of the gap, is somewhat larger than at Kaunakakai, and this is, indeed, to be expected, for its position is more open to the northeasterly trade winds. On the north side of the gap precipitation is still further increased, as is indicated by the strong growth of grass, remaining green up to June 1.

At Molokai ranch, at an elevation of 850 feet and only a short distance from the gap, records have been kept by Messrs. Schleifer and Monroe since January, 1899, with the following results:

Rainfall at Molokai ranch.

Month.	1899.	1900.
	Inches.	*Inches.*
January	2	2.69
February	3.75	4.14
March	3	1.36
April	1.90	5.30
May	.50	.83
June	(a)	2
July	(a)	.....
August	(a)	.....
September	(a)	.....
October	1.23	.....
November	1.29	.....
December	1.71	.....
Total recorded	15.38	.....

a No record.

The figures for 1898–99 are incomplete. The season was one of great deficiency in rainfall, and this dry winter was followed by an exceptionally dry summer. The total for the rainy season 1899–1900 is 20.55 inches, indicating an annual rainfall at this place of about 22 inches.

At Meyer's ranch, at an elevation of 1,400 feet, about 2 miles northeast of Molokai ranch, records were kept for some time by Mr. R. W. Meyer, but I have only been able to obtain those of 1891. This year was, as the records show, an exceptionally dry one on Oahu and Maui. At Honolulu 23 inches fell that year against a normal rainfall of 38 inches. It is believed that the latter figure represents the normal rainfall at Meyer's ranch.

Precipitation in 1891 at Meyer's ranch.

	Inches.
January	7.65
February	3.28
March	.36
April	4.35
May	1.63
June	None.
July	None.
August	None.
September	None.
October	4.40
November	.20
December	1.26
Total	23.13

Above an elevation of 2,000 feet in this part of the island almost daily showers occurred from April 1 to May 28, 1900, and this is probably the normal condition during the winter months. Dry and warm weather prevailed from May 28 to June 8, when light showers fell. Again, on June 23, 26, and 27 there was a considerable amount of rainfall.

Regarding the quantity of rainfall in the mountains there is scant information. The annual precipitation probably reaches 100 inches at elevations of 3,000 and 4,000 feet and is not far from this amount over a considerable area on the north slope on the headwaters of Waikolu, Pelekunu, and Wailau.

It has been asserted that the rainfall on Molokai is decreasing. As far as the data go there is nothing to prove such an assertion. It is no doubt true that the island formerly supported a much denser population; this is indicated, for instance, by many old garden patches at streams which are now dry or carry water only intermittently. All this is, however, most probably directly chargeable to the destruction of the forests and the following irregularity or disappearance of the water supply.

SOILS.

The soils of Molokai are similar to those of the other islands of the Hawaiian group and are usually of great fertility. They may be divided into residual and sedimentary soils.

The residual soils result from the gradual decomposition of the basaltic lavas and are usually deep red, very rich in iron and in substances necessary for plant growth.

The sedimentary soils are partly of a deep-red color, partly dark brown, and not very different in character from the residual soils; they consist, in fact, of the same substance merely transported and redeposited. In a few places along the immediate coast line are small areas covered by coral sand, consisting largely of carbonate of lime, usually more or less mixed with detritus from the hills.

The west end of the island contains a very great amount of good, smooth land, with excellent soil. In fact, the larger part of Kaluakoi is of this character, excepting the southern slope of the long ridge extending from Mauna Loa to the light-house, the extreme northern and western portion, and the steep slope extending from Mauna Loa northward to the sea. The soil is residual in character. Unfortunately there is no feasible way of bringing water on this part of the island. It is at present used for sheep ranches and cattle range, being covered by a fine growth of nutritious grasses.

The finest body of agricultural land on the island is situated in the great gap, and has an area of about 14,000 acres. The principal problem of the water supply of the island is how to bring the water from that part which receives an abundant precipitation to this arid portion containing the rich soils. This area of gently rolling hills is covered by a deep-red soil unexcelled for purposes of sugar growing. To a great extent it is a sediment soil, as shown, for instance, along the western plantation fence near Mauna Loa Creek, where it follows the cane planted January, 1900. At this place a depth of from 20 to 30 feet of fine soil and disintegrated washed gravels is observed, resting on basaltic lava. This formation no doubt underlies a large portion of the cane lands. A part, however, of the eastern area on the rising hills is covered by residual soil derived from rock in place.

On the south shore there is a strip of low cane land near the coast at Palaau, but the main body of deep soil does not begin until an elevation of about 200 feet is reached. The total area of cane land at Palaau, below an elevation of 50 feet, is 374 acres.

Above an elevation of 800 feet, on the east side of the gap, there is, between the deeply incised canyons, a considerable amount of smooth land covered by grass and underlain by rich soil; but besides being cut up these areas are, by reason of their elevation, less suited for sugar cane, though well adapted for other crops. Thus, at an elevation of 1,400 feet, on the Meyer ranch, coffee is successfully cultivated in shady places without irrigation.

East of this point the island contains a relatively small amount of economically valuable soils. On the south coast the rocky slopes reach almost to the sea, leaving only in places narrow fringes of level land. On the north side the mountains, as indicated above, are very precipitous, and there is no arable land except small patches along the coast at the mouths of the rivers.

At high elevations the rock is, as a rule, much decomposed and retains water much better than do the stony slopes lower down. In the high swamps the mud is rarely over 2 feet deep, and solid, though decomposed rock comes frequently to the surface. The color of the soil in the swamps is grayish or white, showing that only ferrous oxide, produced by the reducing influences of organic acids, is present. After the swamps have dried up and the trees and ferns die, as has happened

over large areas in the high central parts of the island, this ferrou oxide under the influence of the air rapidly changes to ferric oxide This forms a dark-red, hard-pan area on the surface which is ver detrimental to young plants just rooting. This compact, dark-red so is really an iron ore. A sample examined by Dr. E. T. Allen containe 43.88 per cent of metallic iron. This is one of the reasons why the refo esting of dried swampy areas is such a slow and difficult process.

For some distance east of Palaau there is a strip of sediment lar along the coast containing 110 acres. Toward the sea this is joine by a salt marsh and toward the north by a rocky slope, which in par however, can be planted. Near the cocoanut grove, 1¼ miles west Kaunakakai, are 150 acres of excellent level soil underlain by 5 to feet of coral which again rests on solid lava. At Kaunakakai abo 100 acres of level rich soil are available. Between Kawela ar Kaunakakai is a narrow strip of soil—mostly coral sand—which covered by a thick growth of algarobas. At Kawela there is a consi erable extent of sandy soil, practically all of which belongs to sma native holdings. At Kamalo again several hundred acres of goo soil are available, and from this place to the east point of the islar a number of more or less extensive flats follow the coast, many which are cultivated on a small scale. The lower part of the valle of Halawa, Wailau, Pelekunu, and Waikolu contains a small amou of lands chiefly devoted to the growing of taro on a small scale.

VEGETATION.

In regard to vegetation, the southern side of the island may l separated in several zones. There is first the immediate coast fring distinguished by cocoa palms and algarobas; the barren zone; tl belt of the grass lands; and finally the high forests.

The southern coast is fringed by a narrow, bright-green zone thick and luxuriant algaroba trees (a variety of mesquit) whi furnishes excellent firewood. The abundant bean pods of the tree a used as forage for cattle and horses. This strip is only a few hundr feet wide, but extends from Kawela Creek, almost without interruptio to a point a few miles west of Palaau. The western coast suppor at Papohaku a few small and stunted groves of the same tree; tl northern and eastern coast is too humid to permit the growth of th essentially arid-land tree. Occasionally, near springs at the seashor the lahale trees appear, with clumps of bare trunks and palm-like tuf of leaves. This produces a fiber used for the manufacture of hat etc. There is a large cocoanut grove one mile west of Kaunakaka Few groves of this palm are planted east of this on the southern coas though many places are excellently adapted for this purpose. B thickets of the obnoxious weed Lantania grow on the coast nea Kawela.

The barren zone of rough lava bowlders, with only a few bushes adapted to a dry climate, extends along the south coast, from the western point of the island to beyond Kamalo on the east. At Palaau it reaches an altitude of 200 feet; at Kaunakakai, 1,000 feet; and at Kawela, 2,000 feet. Toward Mapulehu the grasses reach sea level.

The pasture lands are covered by a thick carpet of manania (a variety of Bermuda grass) or delicate tufted Pele grass. Above a certain elevation (about 500 feet on the west end) these give way to annual grasses. Almost the whole of Kaluakoi, or the west end, is covered by pasture land; likewise the gap, excepting the arid strip near Palaau. Both of these areas are practically treeless. During the arid season the grass dries up. In the creeks and canyons east of the gap are found groups of kukui trees, with their smooth trunks and yellowish-green foliage bright with an almost silvery sheen. This is also called the candle tree, on account of producing a nut rich in oil. Many of these groups show signs of damage by cattle.

Isolated wili-wili trees are also noted, with their coral red bean and peculiar habit of shedding their leaves in the summer. Scattered cactus trees and hau bushes complete the meager flora of this zone. The finest and healthiest groves of kukui trees are found in the different branches of Meyers Creek above Meyer's ranch at elevations of about 1,000 feet. Parasitical ferns grow in profusion on the tree trunks. Papaia trees and coffee bushes do well wherever planted in these shaded canyons.

As the elevations increase, the grassy ground gradually becomes more swampy. Near Meyer's ranch the pastures are diversified by thick bushes of wild guavas, and ferns grow luxuriantly in the little gulches. Going upward from Meyer's ranch over swampy pastures and partly decayed forests, sometimes crossing little canyons thick with a growth of ferns, one is suddenly and unexpectedly stopped by the great precipice, the northern pali, here descending abruptly 1,500 feet to the sea, and showing along its steep escarpment the broken succession of the dark lava flows (Pl. IV, *A*). Far below, a silvery white fringe of breakers marks the shore. A rocky peninsula extends at the foot of the pali, and on its western side we notice a prosperous-looking town with regular streets and white cottages. Several churches and larger buildings are also seen, and many of the houses are surrounded by bright green gardens. This is the leper settlement of Molokai. A steep and somewhat dangerous trail leads down to the town. The inmates of the settlement are not allowed south of the pali, and at the little gate at the summit of the trail the unfortunates confined in the settlement often meet their friends.

In this vicinity the forests begin at an elevation of 2,500 feet, but the trees are in poor condition and on large areas are dying. It should be observed that all forests on this island grow on swampy ground. Open forests with trees growing on dry ground do not exist. The

lehua, a myrtaceous tree, in several varieties is most abundant. has dark-green foliage and bright-red flowery tassels during the spri months. The height is usually up to 30 to 40 feet. More comm on the north slope is the ohia or mountain apple, and the koa w its exceptionally hard wood. Around the moss-covered roots, f quently branching above ground, cluster the thick ului ferns (*Gl chenia*), and intermingled with the lehuas rise the pulu ferns (*Cibotiu* with their widespreading fronds up to 15 feet high. The whole interwoven with a mass of tough eea vines (a kind of *Pandanus* climbing screw pine) to a thicket which usually is almost impenetral except along the beaten trails.

From Meyers Lake to east of Kaulahuki the forests, once said to thick and healthy, are in a decaying condition. Kalamaula swai is now partly dried. Around Kaulahuki extends a comparatively d high plateau, and the peak itself is easily accessible. Going up o\ this plateau, rolling, grassy, and cut by sharply eroded little canyo one comes suddenly to the great alcove canyon of Waikolu. T plateau is cut off sharply as with a knife; the eye sweeps down t black abyss of the precipices of the Upper Waikolu, and then do the V-shaped canyon to the sea. Narrow streams of water desce the faces like silvery threads on a black background. But at eve place where there is a possibility of foothold a rank vegetation cov the rocks, and where the walls become a little less abrupt there i solid area of dark-green foliage. At the brink of the canyon t mornings are often calm and clear, but before noon the sky and t sea mingle in one hazy bank and the strong trades drive drippi mists and intermittent showers over the swampy highlands.

A short distance east of Kaulahuki the horse trail ends and t whole country is covered by thick, healthy vegetation. Above Kawe the forests formerly descended far below Kolekole hill to an elev tion of 3,000 feet. In its normal healthy condition the forest n extends along a width of only one-half mile on the southern slo Traversing this thick swamp, clambering over slimy, moss-cover roots, and wading through deep mud, one suddenly emerges on t Pelekunu pali at an elevation of 4,500 feet. From this point can seen the whole of Pelekunu drainage and part of Wailau, a gree impenetrable wilderness bordered by nearly perpendicular clif Trails are said to cross the island into Waikolu and Pelekunu, b they are dangerous and difficult.

From Mapulehu an exceedingly bad though not particularly da gerous trail leads over into Wailau. Guided by Mr. Theodore Mey I ascended the steep grassy slopes from Mapulehu to a more gent sloping path between narrow canyons, along which kukui, wi orange, and guava grow in profusion. We made camp at the ed of the forest 1,550 feet above Mapulehu. The next morning at su rise a magnificent view was obtained of Haleakala, Maui's gre

volcano, with its gigantic crater, seemingly only a few miles distant, but within a short time the usual clouds again hid the summit of the mountain. The track now enters the forest and ascends 1,200 feet in 1 mile, through lehua roots and mud, to Wailau Gap, which has the comparatively low elevation of 2,750 feet. The forest seems healthy, but Mr. Meyer states that it is much more open than formerly, probably due to grazing of cattle. In this part of the island there are, however, few cattle compared to the number kept in the western part. From the summit the extensive view over Wailau Valley reveals the same impenetrable sea of dark-green forest relieved by bright patches of wild bananas and kukui groves. Over slippery moss-covered rocks the trail descends 2,000 feet in 1 mile to the east fork, which may be followed for half a mile, by wading through water or jumping from rock to rock, down to the junction of the two forks, at an elevation of about 600 feet. Some distance before the east fork is reached we passed an abandoned kuliana, or native settlement, with a taro patch and a few exceedingly welcome orange trees.

The Wailau is a comparatively large stream, and its waters rush with torrential force in the narrow canyon. There is no further cultivated ground until near the mouth of the river, where considerable taro is grown and sent over by steamer to the leper settlement, partly whole, partly crushed to so-called "paiai" and packed in ti leaves. Pl. III, *B*, represents the native crew of the little steamer *Mokolii* engaged in loading paiai. We returned the same day to the camp above Mapulehu. The excursion makes an extremely arduous day's work.

CAUSES OF DECREASE OF FOREST AREA.

Many theories have been advanced as explanations of the decay of the forest. It has been attributed to cattle, deer, and goats, to decrease of rainfall, and to a disease of the trees.

It is evidently true that for many years the island has been overstocked, especially the good pastures at higher elevations, and it can easily be understood how the damage to the trees is effected. The cattle do not kill the trees directly, but they destroy the thick growth of ferns and grass which protects the roots and which is evidently essential to the life of the lehua tree. They also eat the young trees just coming up from seed. This has assuredly been the most prominent cause. But in many canyons where cattle scarcely can find their way, as well as in some parts of the swamps near the Pelekunu pali, the lehua trees are also dying, which indicates that the tree is besides suffering from some insect or fungus. The deer do less harm than the cattle, but it may nevertheless be well to keep their number within reasonable limits. In lower elevations goats abound, which should be removed as thoroughly as possible, for they completely destroy the already scant vegetation. Sheep have lately been confined to the western end (Kaluakoi), which seems most suited to them.

All in all, I believe that the cattle, in part aided by the disease referred to, are responsible for the decay of the forests and that it is not necessary to assume any material changes in climate. As mentioned, there is no such decay noticeable at Mapulehu, where very few cattle have been pastured. In consequence of the drying up of the swamps, the rainfall runs off rapidly and the streams become more intermittent and torrential in character, as indeed is very clearly marked in the case of Kawela. To remedy these conditions, I can only suggest the exclusion of cattle and other fern-destroying animals from the upper mountain region, which may cause the swamp ferns and lehuas to grow up again. The hard pan mentioned on page 20 is a serious obstacle to reforestation. Planting certain areas of land below the swamps by eucalyptus, acacia, or Monterey cypress would remedy matters to some extent.

FAUNA.

As well known, the native Hawaiian land fauna is exceedingly scant. A number of small birds inhabit the forests. Excepting a few centipedes, the objectionable insects are few in number. Many varieties of tree snails are found, often of beautiful color and delicate shell sculpture. More species of these are said to occur on Molokai than on adjacent islands.

The introduced animals are deer, goats, and cattle. The deer are of the spotted Japanese variety and have multiplied rapidly, so rapidly, indeed, that it has been found necessary to attempt to reduce their numbers, as they do considerable damage to the vegetation. Their principal range is on the high plateaus a few miles east of Meyer's ranch at the edge of the forest. The goats have likewise proved a nuisance, and it is difficult to keep in check their rapidly growing numbers. They chiefly range, practically wild, over the arid portion of the southern slope. It is surprising to observe their gymnastic performances when a band of them is scattered browsing on the ledges of canyon cliffs which a casual observer would pronounce perpendicular. The sheep kept on the Molokai ranch are chiefly confined to the western end of the island. Most of the cattle are now kept on Molokai ranch, including the west end, the gap, and a part of the southern slope as far as Kawela. Some of them run almost wild, but attempts are made to reduce that number, and also to keep them off the high forest areas. The island has been heavily overstocked with cattle, but the number is now reduced. East of Kawela there are comparatively few. For a limited number the western half of the island is a most excellent range.

CULTURE.

Tradition has it that in former days Molokai supported a far greater number of inhabitants than at present, and, further, that the forest *covered much greater areas*, even occupying part of the now treeless *west end of the island*. While, as explained above, it is doubtful

whether the rainfall has decreased, it is certain that with the destruction of much of the forest areas an equalizing element of much importance has been eliminated. From one end of the island to the other the coast abounds in stone fences and heiaus or square inclosures of stone connected with the worship of the gods. Evidences of old cultivation are apparent at a number of now arid places. Abandoned farms are found in the valley of Wailau; on the Pelekunu, a mile or two from the coast, old abandoned plantations of pineapples were noted. Such cultivation as now may be carried on by the natives is shiftless and imperfect. Taro is raised in the Lower Wailau and Pelekunu. Rice fields are cultivated by Chinese at intervals along the southern coast. A few small cocoanut groves are planted, but there is only one large grove, near Kaunakakai, said to have been planted by Kamehameha V. Small scattered kulianas contain a few oranges, mangoes, and papaias. On the whole, it is clear that with proper care and industry the island could support a far greater number of people than dwell on it at present. To some extent this undesirable state of affairs is doubtless due to the consolidation of properties into larger holdings for prospective sugar cultivation. But there is also a decided tendency of the natives to sell their small holdings and to move away to centers like Honolulu. The ranch of the Meyer Brothers, located about 5 miles north of Kaunakakai, shows what can be done even with comparatively small holdings when intelligent care is applied. Cattle are raised here, as well as some coffee and other products.

The population of the island aggregates about 2,400; but over 1,000 of this number are located in the leper settlement on the northern coast, established in 1865 and embracing about 8,000 acres. Of the remainder, several hundred are probably Japanese laborers, as the census was taken in 1900, when there were many of this class at Kaunakakai and Kamalo, so that there would remain only about 1,000 people scattered at Pelekunu, Wailau, Halawa, and the southern coast as far west as Kawela, for along the real arid part of the coast there are but few inhabitants. The total assessed value of Molokai was only $250,000 in 1897. In 1900 this figure had increased to about $686,000, due to the projects for sugar plantation advanced that year. In 1901, after the partial failure of these attempts, the assessed value decreased to $427,000. The Molokai Ranch Company, a corporation, controls the larger part of the lands on the western part of the island as far east as Kawela, and make a successful business of raising cattle and sheep on the extensive grass lands.

The American Sugar Company, closely connected with the Molokai Ranch Company, began operations in 1898 and 1899, controlling nearly the whole of the rich body of land in the gap, and the coast as far east as Kawela. It was proposed to bore for water at Kaunakakai, where 10,000,000 *gallons* per twenty-four hours (15.47 cubic feet

per second) were expected, and to raise this by means of pumps to an elevation of 400 feet to a ditch conveying it to the cane lands below the 350-foot level. It was further intended to obtain 20,000,000 gallons (30.94 cubic feet per second) 1 mile east of Kaunakakai and conduct it to a point 2½ miles away, where the water was to be lifted 500 feet to a short ditch conveying it to the lowest point of the gap, whence it could be distributed on both slopes. Eighty acres of seed cane were planted on the Kaunakakai flats and irrigated from a well giving 1,000,000 gallons in twenty-four hours (1.55 cubic feet per second). The failure of the Kaunakakai wells to produce the amount expected caused a change in the plans. It was decided to bore wells at the mouth of Kawela Gulch and raise the water about 70 feet to a cement-lined aqueduct, which should convey it to the high-lift pump mentioned above. Here, too, however, the quantity obtainable at one point seemed insufficient, and difficulty was experienced in avoiding contamination by salt water. Attempts were also made to find water by deep borings. In 1900 the company decided to abandon operations for the time being, and thus the problem how to obtain water for the rich sugar lands at the gap still remains unsolved.

The Kamalo Sugar Company controls the coast from Kamalo to Mapulehu. In this distance there are a number of smaller flats aggregating a considerable area. It was proposed to utilize these for sugar cane by wells bored along the coast and raised to a ditch about 70 feet above sea level. A small area of sugar cane for seed was planted at Kamalo and irrigated by means of a permanent small stream at the head of Kamalo Gulch. The water was taken out a short distance east of Kolekole Peak and temporarily conducted down in a ditch along the ridge. As Kamalo Gulch often contains running water, it was also proposed to utilize this source.

WATER SUPPLY.

GENERAL PRINCIPLES.

The fundamental law governing the water supply is that the only source of fresh water is the rainfall. A part of this rainfall is carried off by evaporation, another part by the streams, while a third and largest part sinks into the ground and gradually finds its way to the ground water, which permanently saturates the rocks below a certain level.

But on this small island, built up of extremely porous rocks, and surrounded by salt water, peculiar conditions result. In the absence of any impermeable stratum or basins filled by clayey material, such as, for instance, exist on Oahu, there is nothing to prevent the sea water from penetrating the rocks freely and assuming a level differing but little from the sea level. Below a certain level there is indeed no reason to expect *anything* but salt water.

On the other hand, the rain water also sinks freely through the porous rocks until it meets the sea water. Here, at the permanent water level, it is held by the counter pressure of the sea water, and in fact rests like a sheet on the same. Between the underlying salt water and the fresh water on top of it there is an intermediate zone of varying width in which the two mingle to form brackish water. The fresh water, always receiving additions from above, is slowly but steadily moving to the only outlet it can find—that is, to the springs located along the sea shore, just above or a little below sea level.

The surface of salt water is, apparently, near the coast on the south side of the island, about 160 feet below the surface of the ground. Inland this level sinks, and is also doubtless deeper on the north than on the south coast. The permanent surface of fresh water rises inland very slowly, so that a mile or more inland the water in wells may stand only a foot or two above sea level. Only at Kawela, a few hundred feet from the coast line, is the water level from 2 to 3 feet above mean sea level, and in this place a more abundant underground water supply is found than at any other point west of it. This generally low level of ground water is a distinctly unfavorable sign, pointing to small precipitation and water supply.

The one feature favorable to the percolation of the water to the southern coast line is that the lava beds all slope in this direction—that is, toward Palaau, Kaunakakai, and Kawela—thus to some extent guiding the water in this direction.

On the north coast the permanent water level is much higher, as indicated by the number of strong springs coming out at elevations of from 300 to 500 feet above sea level.

Above the surface of the ground water there may be some movement of water in cracks and fissures, but there is no permanent and abundant supply, certainly not on the south slope. Thus, tunneling on this slope is not apt to develop any considerable amount of water, though it may open some small fissures in which water circulates. As a matter of fact, very little water has been developed by the several tunnels driven near springs at higher elevations. If it were possible to drive a tunnel with very slight grade from sea level or from near the same, such an opening might develop a considerable amount of ground water; but this would be attended with many difficulties.

There is considerable irregularity in the amount of water available below the ground-water level. The porosity of the rock changes very rapidly; open, loose agglomerates are laterally adjoined by hard, much more impervious basalts. Further, the drainage conditions vary, the ground-water surface rising higher in one place than in another; thus in closely adjoining wells there may be great difference in the amount of water available from the same level.

The water from the flowing streams and from the springs emerging at high elevations contains practically no chloride of sodium, this being *the only saline constitutent* necessary to consider.

In the ground water along the coast the salinity is decidedly higher except where the ground water is mingled with water sinking from intermittent streams. The salinity increases with the distance from the center of maximum precipitation. Thus, at Palaau the water contains 90 grains, at Kaunakakai 50 grains, and at Kawela 25 grains per gallon.

In the following pages the available water resources will be described under the head of springs, streams, and wells.

SPRINGS.

The springs coming out on the southern slope of the island may be divided in three classes: First, those emerging at sea level. These are very numerous, and often, by reason of their vicinity to seashore, more salty than the normal ground water. Second, those appearing at elevations from 1,000 to 2,500 feet. Between the sea level and 1,000 feet no permanent springs appear, at least not west of Kamalo. Third, those of the summit region feeding the permanent streams. These will be mentioned under the heading of "Running streams."

On the north coast springs are more numerous and larger and emerge at any elevation. Strong springs appear in the Wailau and Pelekunu at from 300 to 600 feet above sea level.

SPRINGS ON SEASHORE.

No permanent springs are known on the whole north and west coast of Kaluakoi or the west end. A small spring has long been known to emerge on the south side of the ridge, near the summit, 2 miles east of the light-house, at at elevation of 180 feet, but it dried up in 1898 and has not been running since. At Waiakane, well below high tide, a strong spring of fair water appears.

The next important locality is Palaau. In the grassy marsh below the deep well big springs come out for a distance of 700 feet. Many old taro patches indicate that this water has been used. One of these springs flowed about 60,000 gallons a day (0.09 cubic foot per second), and the aggregate flow must be large. A sample yielded 10 grains of sodium chloride per gallon. On Naiwa, between Palaau and Halfway Camp, near a lone cocoanut tree, strong springs emerge from clefts in the basalt rock at the beach, 1 foot above high tide the total visible flow may be as much as 170,000 gallons in twenty four hours (0.26 cubic feet per second), and the salinity is 127 grains.

Half way between Palaau and Kaunakakai again a number of smaller springs appear, with a salinity of 86 grains per gallon. They emerge 1 or 2 feet above high-tide level.

The next locality is Cocoanut grove, 1 mile west of Kaunakakai when very strong springs come out from the sand at the shore for a distance of 150 feet. The total flow is difficult to estimate, but it may

be over 200,000 gallons in 24 hours (0.31 cubic foot per second). The water contains 115 grains of sodium chloride per gallon.

Near Kaunakakai there appear to be no springs of importance, but 1 mile eastward, close to the road, a strong spring comes out from the basaltic rock at the foot of a bluff, 1 foot above sea level. Flow, approximately 6,000 gallons in 24 hours (0.01 cubic foot per second). The water contains 76 grains sodium chloride per gallon.

From this place to a point 1,000 feet east of Onini triangulation station no springs were seen at sea level, though wells find water at a depth of a few feet in most places, the sodium chloride in these amounting to about 115 grains. At the locality just mentioned a strong spring appears, and for a distance of several hundred feet much water comes out along the beach. The total flow must exceed 200,000 gallons in 24 hours (0.31 cubic foot per second). The sodium chloride amounts to 72 grains per gallon. A little water comes out east of this point as far as the end of wall around the fish pond. Again, small springs appear at the kulianas, just west of the mouth of Kawela Gulch. All of these springs east of Onini are under water at high tide.

The largest springs noted appear in the rice field east of Kawela Gulch, at the foot of a little bluff; they are 1.5 feet above sea level, and the aggregate volume of water measured by the discharge from the rice field is 450,000 gallons in 24 hours (0.70 cubic foot per second). The water contains 12 grains of sodium chloride per gallon. East of Kawela the coast was not examined in detail. Probably the coast springs continue all the way to Halawa and are fully as strong as at Kawela.

HIGH-LEVEL SPRINGS.

On the south slope, west of Kamalo, the springs issuing between 1,000 and 2,400 feet above sea level are exceedingly few in number.

The gulch heading north of Meyers at Puu Lua and emptying into the sea after flowing a few miles westward contains three springs. The principal one, at an elevation of 1,300 feet, yields at least 30,000 gallons in twenty-four hours (0.05 cubic feet per second), has no salt, and on May 21 flowed on the surface for a distance of at least one-half mile. Water comes out for a distance of about 1,000 feet; at the head two short tunnels have been run into the side hill without increasing the flow. At this place there is a watering trough, but the spring is said to be apt to run dry toward the end of the dry season. Another small spring inclosed by a stone wall is found in the next gulch just below Puu Lua. Lower down in a tributary to the same gulch, at an elevation of 1,000 feet, a little permanent water trickles out from the side and supplies a watering trough.

In the same vicinity, on Meyer's ranch, are two permanent springs. The first, 1,500 feet east of the trail to the leper settlement, at an elevation of 1,500 feet, yields continuously about 20,000 gallons in

twenty-four hours (0.03 cubic feet per second). The second, deve oped by a tunnel 300 feet long, drains toward Meyers Gulch and fu nishes about 40,000 gallons (0.06 cubic feet per second), nearly all which was developed by this tunnel.

A well-defined spring is that of Kapuna, at an elevation of 1,6 feet. This probably yields about 40,000 gallons (0.06 cubic feet p second), which is conveyed in a pipe line to the Molokai ranch. Tl water contains 3 grains of sodium chloride per gallon. It is perm nent in all seasons according to reports. A short tunnel has been r in under the bottom of the gulch, but it failed to develop any add tional amount of water.

In that branch of Luahine Gulch heading at Hunter's cabin, at tl old wagon road leading up to the summit, a spring appears on tl west side at an elevation of 2,400 feet, 30 feet above the bottom the gulch. Its permanency is indicated by a bunch of wild banan growing close by. The flow was measured on May 28, and was foun to be about 77,000 gallons a day (0.12 cubic feet per second). Tl water is practically free from salt, but, according to reports, dwindles down to a fraction of this amount during the driest part the season. A tunnel 800 feet long has been run in under the hill i a north-northeast direction below the Kalamaula Swamp, but ver little additional water was developed. The water comes out fro the side and roof for short distance, while the rest of the tunnel simply moist, giving no flowing water.

The only remaining spring at middle elevations is on Kawela, ne its east boundary, in the gulch near Foster's mountain house, at a elevation of 2,500 feet. The water, which is pure and cold, amounte to 10,000 gallons a day (0.02 cubic feet per second), when visite but the amount is less in very dry weather. From this point t Halawa no detailed examination has been made, but it is probab that springs are somewhat more frequent. At Mapulehu the swamp forests descend to 1,400 feet above the sea, and many springs a found at their lower edge.

RUNNING STREAMS.

STREAMS OF THE NORTH COAST.

On Kaluakoi there are no permanent streams; the gulches conta water only for a short time after heavy rains. Mauna Loa Gulc emptying near Palaau, is the only one in whose upper course a lit water runs during the larger part of the rainy season.

The gulches on the north coast west of the leper settlement a also dry except during heavy rains. The running streams to be co sidered are as follows: On the north coast, Waihanau, Waiale Waikolu, Pelekunu, and Wailau; at the east point, Halawa; on t south slope: Meyers, Kaunakakai, Kawela, Kamalo, Mapulehu, a *Waialua gulches.*

Waihanau.—The lower part of the Waihanau is a deep recess cut back from the pali, and over the edge of this recess, as indicated on the map, the stream flows in a series of falls. In the lower part of the valley the stream does not run during the summer. The upper part, which alone is considered here, has a drainage area of only about one square mile, but receives a great deal of rain water. Swamps line its borders, and much water comes in from springs on the sides of the abrupt canyon in which it flows, and which has a depth of from 300 to 500 feet. The grade is about 100 feet in 2,000. In the upper portion the stream is permanent though low in the dryest part of the season. I am informed by Mr. D. Center, the manager of the plantation at Kaunakakai, that when at its lowest stage the water will fill a 4-inch pipe lying nearly horizontal. This would correspond to about 80,000 gallons in twenty-four hours, (0.12 cubic feet per second). When visited on April 25, the flow was about 2,500,000 gallons a day (3.87 cubic feet per second), at an elevation of 2,046 feet. The weather was showery. On June 22, after three weeks of uninterrupted clear and warm weather, it flowed 1,500,000 gallons (2.32 cubic feet per second). On June 25, during the beginning of showery weather which continued for three days, the flow was 8,500,000 gallons (13.15 cubic feet per second). These results were obtained, as all of the following, at places where the stream ran with slight grade above and fell over an easily measurable natural weir, and should be accurate within 10 per cent. I conclude that the stream can be relied on for 3,250,000 gallons per twenty-four hours (5.03 cubic feet per second) from November 1 to June 1, for 1,000,000 gallons (1.55 cubic feet per second) from June 1 to August 1, and for at least 100,000 gallons (0.15 cubic foot per second) from August 1 to November 1.

Waialeia.—This stream has formed a deep recess from the pali, shorter but wider than that of the Waihanau. Over the nearly perpendicular wall of this recess it falls in cascades. The water in the lower part of the valley sinks during the dry season. Only the upper part above the precipice is here considered; it forms a small canyon extending back for a mile to Puu Kaeo. The watershed is only one-half of a square mile, but the supply is permanent, being fed by springs.

During the driest part of the season it fills, according to Mr. Center, a 2-inch pipe laid nearly horizontally. This would correspond to about 16,800 gallons in twenty-four hours. Measured May 24, during showery weather, at an elevation of 2,820 feet, a flow of 400,000 gallons (0.62 cubic feet per second) was obtained, which may be taken to correspond to average flow from November 1 to June 1.

Waikolu.—The Waikolu is a still larger and deeply cut canyon, surrounded near its head by almost perpendicular precipices, 2,000 feet in height. From the summit region belonging to its drainage three streams fall *in grand* cascades over these precipices. The

stream carries permanent water, which is used in the bottom of the valley for growing taro, the water rights of the lower part belonging to the leper settlement.

The area drained by the western branch of the Upper Waikolu is only one-half of a square mile, but practically all of it is swampy lands, insuring a good supply, permanent, though small, even through the dry months. The stream has cut a small canyon about 300 feet deep in this swampy plateau. The water was measured at an elevation of 3,645 feet on May 31, after three days of warm, clear weather following showery weather, which are practically normal conditions. The flow was 1,250,000 gallons (1.93 cubic feet per second), which may be accepted as the normal for the rainy season. The two other branches of the Waikolu head on the swampy, almost inaccessible plateau between Waikolu and Pelekunu.

Pelekunu.—Like the others on the north coast, this stream has cut a deep, alcove-like recess from the pali along the coast, continuously surrounded by precipices from 2,000 to 3,000 feet high. The highest part of this precipice is toward Kawela, while a narrow backbone, with an elevation of 2,500 feet, separates it from the headwaters of the Wailau. The watershed has an area of 7 square miles. In its lower course the grade of the stream is about 100 feet per 2,000, but above elevations of 1,000 feet it becomes very steep. The whole area is covered by extremely dense vegetation of ferns, lehuas, kukui, ieie vines, and in many places wild bananas and mountain apples. Many large springs swell the lower course of the Pelekunu, coming out at elevations of from 300 to 600 feet. At an elevation of 350 feet the stream forks, the west branch again forking above this at an elevation of 425 feet.

On June 15 I visited the lower course of the river, ascending from the coast, there being no safe trail from the south side of the island to Pelekunu. The landing at Pelekunu is difficult, and on account of the heavy surf, practically impossible during the winter months. The weather for two weeks had been clear and warm, following a period of showers. The east branch of Pelekunu, measured at an elevation of 400 feet, contained 5,300,000 gallons (8.20 cubic feet per second). The middle or main branch, measured at an elevation of 475 feet, contained 11,700,000 gallons (18.10 cubic feet per second), while the west fork at the same elevation contained 4,500,000 (6.96 cubic feet per second), making a total of 21,800,000 gallons in twenty-four hours (33.73 cubic feet per second), from a watershed of 4 square miles. The question of minimum flow is a difficult one to answer without any measurements during the driest part of the season. A total of 5,000,000 gallons (7.74 cubic feet per second) at an elevation of 500 feet is certainly conservative; more probably the least flow would be 6,000,000 or 7,000,000 gallons (9.28 or 10.83 cubic feet per second). More observations during September or October are necessary to settle this point.

Wailau.—This, the largest stream of the island, is in general characteristics very similar to the Pelekunu. Its drainage area is slightly larger and is covered by the same dense vegetation. Precipices like those at Pelekunu, though scarcely as steep, surround the basin, which is narrower toward the sea than toward the head. A difficult foot trail connects Wailau with Pukoo and Mapulehu and crosses the mountain at a pass with the low elevation of 2,800 feet. From the summit gap the trail descends along the ridge between the two principal forks and reaches the east branch at an elevation of 690 feet; then it follows this for some distance and ascending again over the small point Puu o Wailau (elevation 680 feet), it reaches the junction of the forks at 470 feet. At the time of the visit, June 5, clear weather had prevailed for one week over the whole island, following showery weather in the end of May.

At an elevation of 500 feet the east fork contained 7,500,000 gallons (11.60 cubic feet per second), and at the same elevation the west fork contained 14,100,000 gallons (21.82 cubic feet per second), thus giving a total of 21,600,000 gallons in twenty-four hours (33.42 cubic feet per second) from an effective drainage area of 5 square miles. It will be noticed that the Wailau and the Pelekunu differ but little in their total flow; while the drainage area of the latter above 500 feet is slightly smaller, the elevation of its watershed and the precipitation is probably somewhat larger than that of Wailau.

Regarding the minimum flow the same remarks apply as have been made regarding the Pelekunu. Ten million gallons (15.47 cubic feet per second) is a liberal estimate of the least flow; more likely it is 8,000,000 gallons in twenty-four hours (12.38 cubic feet per second).

Several minor streams descend like silvery threads from the pali into the sea between Wailau and the eastern end of the island. Sometimes the strong trade winds dissipate these cascades into mist before they reach the foot of the escarpment.

Halawa.—Very near the eastern promontory the important watercourse of Halawa empties into the sea. Halawa differs from the other streams in flowing in an almost due east direction. Its watershed comprises about 8 square miles; it has its source in the swampy, impenetrable plateaus east of Wailau, and it descends from these in a beautiful waterfall plainly seen from the harbor. For a mile or two above its month it flows in a somewhat open, fertile valley. The minimum flow of Halawa is reported by Mr. O'Shaughnessy, former engineer to the American Sugar Company, to be about 5,000,000 gallons in twenty-four hours (7.74 cubic feet per second).

STREAMS OF THE SOUTH COAST.

Meyers Gulch.—This stream has a drainage area of 16 square miles, the largest on the south coast, but except near the summit it contains no permanent water, *not even* during the winter months. Its canyon

is sharply cut into the grassy plateau to a depth of from 200 to 30(feet, and contains in places thick groves of kukui trees. It empties a short distance east of Palaau. The grade in the lower course i moderate, but above an elevation of 1,500 feet it increases rapidly an the canyon contains many abrupt falls. The uppermost courses of th different branches have again a more gentle grade. At an elevatio of 700 feet the creek branches. The east, or Luahine, fork head with two prongs near the Hunter's cabin, on Kaunakakai land division at an elevation of 3,000 feet; the main branch continues by Meyer ranch, where it is joined by several smaller branches extending u toward Meyers Lake, and 1 mile above Meyers divides again into th Kahapakai and the Mokomoka branches, both of which head at ele vations of about 2,600 feet in Kalamaula swamp.

During the winter of 1899–1900 the water in this gulch reached th coast four times—in December, April, May, and, lastly, June 27 and 2(The volume is considerable, sometimes 5,000,000 to 8,000,000 gallon in twenty-four hours (7.74 to 12.38 cubic feet per second), but th flow subsides rapidly. On June 27 about 5,000,000 gallons came dow in twenty-four hours (7.74 cubic feet per second), while the next da there was but a slight stream trickling along the bed.

The permanent water appears chiefly in the Kahapakai Fork. Nea its head, which is separated only by a narrow ridge from the canyo of the Waihanau, it is fed by strong and continuous springs comin in chiefly from the east side. Between 2,000 and 1,500 feet there is sharp grade. Though the flow is small in summer the water run permanently as far down as Wahii (elevation, 1,475 feet), where on branch of the water pipe supplying the ranch ends. Below this, o May 26, a little water was running, but only as far as the junction (the two forks.

On May 24, in light showery weather, Kahapakai was measured a an elevation of 1,975 feet, and flowed 281,000 gallons (0.43 cubic foo per second), diminishing at an elevation of 2,200 feet to 192,000 ga lons (0.30 cubic foot per second). The same creek, at an elevation (1,975 feet, contained on June 25 (light showers following three week of drought) 155,000 gallons (0.24 cubic foot per second). On May 2(after some pretty heavy showers, the water at Wahii measured onl 151,200 gallons (0.23 cubic foot per second), showing that the max mum flow is at a considerably higher elevation.

The Mokamoka Fork does not contain as much water, nor is it pe manent during the summer. On May 26 it was running only a litt water one-fourth of a mile above the mouth of Kapuna Spring Gulc Its average flow during the rainy season, at an elevation of 2,000 fee may be estimated to be 150,000 gallons (0.23 cubic foot per second The Luahine Fork of Meyers Gulch branches at an elevation of 2,0(feet, the two forks heading on each side of Kalualohe Hill. The we fork carries some water, about 100,000 gallons (0.15 cubic foot p

second), in the rainy season, and is said to run some throughout the summer. The east fork contains the spring mentioned above. The flow begins one-half mile above the tunnel and continues for at least the same distance below it. The maximum flow is perhaps 1,000 feet below the tunnel. On May 30 it gave 135,000 gallons (0.21 cubic foot per second).

Kaunakakai Gulch.—This gulch, debouching at Kaunakakai, has cut a long, narrow box canyon, and embraces a watershed of al out 8 square miles. It has a very straight course and is from 100 to 400 feet deep, the maximum depth being attained at the junction of the forks below Kaulahuki. From the west it receives some deeply eroded tributaries heading at Hunter's cabin, but these are usually dry, even through the rainy season. The main canyon has near the mouth a grade of about 100 feet in 1,500. In its middle course it is very steep, while on both sides of Kaulahuki lighter grades again prevail. The gulch contains running water in its middle and lower course only after heavy rain storms. Occasionally, very heavy freshets flood the plain at its mouth and bring heavy bowlders from the canyon. It is, in brief, a typical torrential stream. During the winter of 1899–1900 it was in flood in December; again in April, and finally in the last days of June, but each time the volume diminished rapidly, and after twenty-four or twenty-eight hours had dwindled to a very small amount. Below Kaulahuki, at an elevation of 2,500 feet, the main canyon forks—one branch, the Kamiloloa, heading between Kaulahuki and Kaeo, while the other, the Makakupaia, heads in the swamps around Hanalilolilo. Both of these branches carry permanent water. Kamiloloa during the period of examination carried water from its extreme head down to a point 3,500 feet above the junction. It is largely spring fed and its permanency is attested by a big bunch of wild bananas growing in the canyon at an elevation of 3,100 feet. On April 29 there was at least 200,000 (0.31 cubic foot per second) or 300,000 (0.46 cubic foot per second) gallons running. On May 31, after three warm, brighter days following showery weather, a flow of 276,000 gallons (0.43 cubic foot per second) was measured at an elevation of 3,100 feet. According to apparently reliable accounts it dwindles in extremely dry weather to 20,000 gallons (0.03 cubic foot per second). The main bulk of the water comes from the Makakupaia Fork, which is fed partly by springs but largely by the water stored in the swamps about Hanalilolilo. Below this point the Makakupaia forks again, both branches carrying water, though the eastern branch contains the larger part of it. The water, as in all of the streams heading in swampy ground, is of brownish color. The flow is continuous, even in the driest season, but, as in the case of Kamiloloa, it dwindles to a small amount. In the rainy season the water runs for a distance of several thousand feet below the junction, and even in the dry season it usually reaches the junction, according to state-

ments of Mr. Theodore Meyer. The stream was measured May 31, under normal conditions, three days of fair weather following showery weather, at an elevation of 2,510 feet. A flow of 450,000 gallons (0.70 cubic foot per second) was obtained.

Onini Gulch.—Though heading at 3,000 feet this gulch is ordinarily dry up to its head, only flowing after heavy rains.

Kawela Gulch.—The Kawela drains a territory of about 3½ square miles. It heads in the swamps near the highest peaks of the island and flows in a narrow box canyon from 100 to 500 feet deep. The grade near the mouth is 100 feet per 2,000, but in the middle course it increases to extremely sharp descents, broken by many perpendicular falls. In its upper course the grade is again less, perhaps averaging 100 feet in 1,000 feet.

Like Kaunakakai, this is a pronounced torrential stream, but it carries considerably more water. During the rainy season its flow very frequently reaches the sea continuously for several days. On an average the Kawela is in flood at least once a month between October and June. There is a great deal of water under its sandy flood plain, and the flow during freshets is depended upon to irrigate the kulianas (small holdings of native settlers) near its mouth. The flood does not stop suddenly, as in Meyers and Kaunakakai gulches, but continues for several days. The volume of water coming down is very large. On May 1, several days after showery weather, the Kawela, 500 feet above the forks, at an elevation of 160 feet, flowed at least 300,000 gallons (0.46 cubic foot per second), which at an elevation of 100 feet diminished to about 100,000 gallons (0.15 cubic feet per second). On May 28 Kawela had been flowing strong for several days; at an elevation of 100 feet there was a flow of 3,000,000 gallons (4.64 cubic feet per second). This gradually diminished, and on June 11 the creek was dry at the junction of the forks. On June 26 the creek was in flood again and continued so for several days, the amount on the day mentioned being at least 6,000,000 gallons (9.28 cubic feet per second).

The Kawela branches three-fourths of a mile above its mouth, and the two canyons have a parallel course only 1,000 to 2,000 feet apart to near their heads. Two miles above the mouth the west fork receive two tributaries which, however, are dry even during rainy season The main west fork heads near Hanalilolilo and carries a little water which rarely reaches the main junction. The ordinary winter flow i continuous for 2 miles below the head to a point below the high-wate fall at an elevation of 3,000 feet, which may be observed from nea Onini station. The flow was measured under normal, average winte conditions at an elevation of 3,350 feet, where its grade is compara tively flat, the result being 190,000 gallons in twenty-four hours (0.2 cubic foot per second). This little stream is probably nearly dry in th fall.

The main or east fork under average winter conditions flows as far down as an elevation of 1,500 or 2,000 feet. By far the greatest volume of its water is collected from the swamps near the head, and during rainy weather its volume reaches 5,000,000 to 7,000,000 gallons (7.74 to 10.83 cubic feet per second). On June 1, after three or four days of dry weather following showery weather, it was measured at an elevation of 3,160 feet, where its canyon has comparatively slight grade. The flow was 1,300,000 gallons in twenty-four hours (2.01 cubic feet per second). On June 19, after three weeks of hot and dry weather, it measured at the same place 350,000 gallons (0.54 cubic foot per second), at about which figure the flow, according to all accounts, remains constant during the summer, though in exceedingly dry weather it may dwindle as low as 50,000 gallons (0.08 cubic foot per second).

Kamalo Gulch.—This stream, together with the two adjoining gulches to the east, receives the drainage of the swamps of the highest mountain region, and in its general characteristics is very similar to the Kawela, though probably carrying a somewhat larger quantity of water. It usually flows at the mouth of the gulch once or twice a month. It is located on the property of the Kamalo Sugar Company, who use it to some extent for irrigation.

East of Kamalo no detailed observations were made. But, as stated above, the rainfall increases steadily in this direction, and grassy slopes descend far toward the sea. Between this place and Halawa the country is comparatively thickly settled. Little flats are common along the shore and little groups of cocoa palms and taro patches appear at frequent intervals. In this distance there are several streams similar to Kamalo and at least one permanent water course, the Waialua. The gulches are numerous and very closely spaced.

WELLS.

The fact that water can be obtained along the coast by shallow wells was recognized long ago, and irrigation on a small scale by means of windmills has been practiced in many places. Water for stock has been obtained in the same manner.

KALUAKOI.

On the western part of the property (Kaluakoi) precipitation is slight and the supply of ground water is accordingly limited and salty in character.

On the north coast, nearly due north of Mauna Loa, is located the Momomie well and windmill, used for watering stock. Here, as at all of the other stock wells, the surplus water is allowed to run back into the well. The depth is 35 feet, water standing at about sea level 30 feet below the surface. The salinity is very high—238 grains per gal-

lon. One mile eastward is an old landing place, where two small houses are still standing. A well 20 feet deep was dug here, but has been allowed to cave.

There are no wells along the coast west of this until Papohaku is reached, at the middle of the west coast. Several wells have been dug in the sandy plain which here follows the coast for about 1 mile. The well and windmill which supplies the stock is one-half mile southeast of Puu o Kaiaka; the depth is 40 feet, the water level, which is equal to the sea level, standing 35 feet below the surface. The water has a salinity of 403 grains to the gallon, thus closely approaching the limit for drinking purposes, even for stock. A quarter of a mile southwest is a smaller well, which probably stands at 200 grains and which is used by the stock men when stopping at Papohaku.

There is no further water until Kamakaipo, where, on the little plain adjoining the sea, a 30-foot well has been dug, the water standing 10 feet below surface. This well proved too salty for use. A smaller well close by, on the trail, is 10 feet deep and contains a little water which has about 150 grains of salt per gallon.

From the light-house to Palaau along the coast fairly good water is much more abundant and the four following wells and windmills are located here on the sandy shore. Alena well and windmill, 1 mile southeast of Waieli, depth 10 feet, salinity about like Kolo; Kolo well and windmill, 5 miles farther east, 7 feet deep, salinity 126 grains per gallon (Pl. II, *A*); Waiakane well and windmill, south of Mauna Loa, 4 feet deep, salinity 150 grains per gallon; Ioli well and windmill, near Palaau, 6 feet deep, salinity 109 grains per gallon, water stands 2 feet below surface.

PALAAU.

A number of wells have been bored near the coast at Palaau, all of them in the vicinity of the proposed site of the mill of the American Sugar Company.

Well No. 1.—This is a 12-inch well at stable 500 feet south of mill site, at an elevation of 22 feet. It is sunk in basaltic lava to a depth of 74 feet, the water standing at about sea level. The water contains 86 grains of salt per gallon. The well was pumped for four days continuously at the rate of 750,000 gallons (1.16 cubic feet per second) without change in water. It supplied the camp with water pumped up to a tank.

Well No. 2.—This is a 12-inch well below the railroad on west boundary of Hoolohua, at an elevation of 125 feet above sea level. It was sunk in basaltic lava to a depth of 140 feet, the water standing at sea level. The water contained 102 grains of salt per gallon when first struck.

Well No. 3.—This well is one-fourth mile east of stable and 100 feet northeast of deep well, at an elevation of 23 feet. It was sunk through

basaltic lava to sea level. In bottom 12-inch well sunk to 50 feet below sea level; very little water near surface. The water contained 86 grains of salt per gallon. This well was pumped for some time—just how long I was unable to find out; probably two weeks—at the rate of 500,000 gallons a day (1.16 cubic feet per second) without increasing the salinity.

Palaau deep well.—This well is located about one-fourth mile east of stable at Palaau, at an elevation of 22 feet above sea level. Total depth when work stopped, May, 1900, 250 feet. The surface formation was basaltic lava. At 180 feet some red tuff was met; at about 200 feet the rock was a coarse, open lava.

The first water, at sea level, contained 86 grains of salt per gallon; at 174 feet 90 grains were noted; at 180 feet from surface the well broke into salt water, which continued until the work was stopped.

Well in Meyers Gulch.—This is one of the oldest wells bored. It is located in Meyers Gulch, one-half mile above the railroad bridge and one mile east of Palaau, at an elevation of 50 feet above sea level. The total depth is 125 feet. Very little water, but of fair quality, was obtained at sea level; at 125 feet the well broke through into sea water.

Wells at mouth of Meyers Gulch.—There are shallow wells on the level plain at mouth of Meyers Gulch, at an elevation but little above sea level. Water stands 2 feet below surface. Water contained 90 grains of salt per gallon.

NAIWA.

The wells on this land are located near the mouth of a small dry gulch, 1½ miles west-northwest of the cocoanut grove. At 37 feet above sea level a shaft 10 by 10 feet is sunk 33 feet close by a 12-inch bore hole sunk to a depth of 70 feet. The first water, which stood at sea level, contained 74 grains of salt per gallon. Deeper, this increased to 90 grains. There is no record of pumping tests.

This locality was selected as repumping station for the high-lift pump intended to elevate the water to the 500-foot level.

KALAMAULA.

On this land, about 1¼ miles northwest of Kaunakakai, are situated the so-called cocoanut grove wells. They are located near the mouth of a little dry gulch, 2,000 feet from the sea, and in the northeast corner of a fine field of arable land which was plowed in 1900 and which it was intended should be planted to cane to be irrigated from these wells. Many good-sized springs come out on the seashore at the cocoanut grove; hence this was probably considered a good location for wells.

Cocoanut grove deep well.—This well is 27 feet above sea level.

Total depth is 343 feet. Diameter is 12 inches. Strata passed through are as follows:

	Feet.
Soil	10
Coral rock	5
Hard lava	25
Porous lava	75
Hard lava	35
Porous lava	193

Water was struck at sea level and contained 80 grains of salt per gallon. At 150 feet the water contained 91 grains, while at 160 feet the bore hole broke through into what was practically sea water and continued in it the whole remaining distance.

Cocoanut grove shallow well.—About 300 feet west of the deep well, at an elevation of 20 feet, is located another 12-inch well, 60 feet deep. One million gallons were pumped during twenty-four hours (1.55 cubic feet per second), the water containing 102 grains per gallon.

Cocoanut grove pits.—Beginning near the above-mentioned well a series of pits have been dug to below sea level. An excavation about 200 feet long and 15 feet deep has been made, and in the bottom of this 10 wells, 8 by 8 feet, have been dug to a depth of 10 feet, though some of them are not yet completed. While there seems to be a considerable quantity of water, no pumping tests have been made, the discouraging feature being that the water coming in ranged from 102 to 104 grains per gallon.

KAUNAKAKAI.

A number of wells have been bored at or near the mouth of Kaunakakai Gulch. Before the advent of the American Sugar Company there were at the mouth of the canyon several shallow wells on the property, on one or two of which windmills were erected. Water of a salinity of about 35 grains was obtained in sufficient quantities for the local needs of the small kulianas at slight depths, about equal to sea level. When undisturbed for some time the water from the upper part of the ground-water sheet contained only 12 grains of salt per gallon. A well at the Japanese hospital at the foot of the lava bluff, 1,000 feet west of the cane-field wells, was sunk to sea level, yielding water which contained 74 grains of salt per gallon.

The deeper wells bored by the American Sugar Company are as follows:

Cane-field wells.—Two wells have been sunk in the cane field from which during the year the 80 acres of cane at Kaunakakai have been irrigated. These wells are situated on the west side of the gulch at an elevation of 22 feet, have a depth of 60± and 75 feet, and are 40 feet apart. Both have a diameter of 12 inches. Water level was

ached after penetrating 22 feet of gravel and soil, the rest of the ells being bored in basaltic lava of varying hardness. Only the 60-ot well is being pumped. A supply of 1,000,000 gallons per twenty-our hours (1.55 cubic feet per second) has been steadily obtained rom it for over one year without increase in salinity, which is from 6 to 96 grains. A sample taken May 4 contained 84 grains. In the ummer of 1899, however, the water was somewhat less salty than in 900, for I find a record of July 10, 1899, showing that after two days f pumping from the first well (No. 1) the water contained 68 to 70 grains of salt per gallon. When the centrifugal pump, which now aises the water from the 60-foot well to an elevation of 40 feet, was connected with both wells the salinity increased to over 100 grains, showing that the deeper well had tapped some salty water.

The settlement well.—This is the most southerly of the long row of wells on the east side of the gulch. The elevation of the ground is 25 feet. The 12-inch well is 60 feet deep. The strata penetrated are largely soil, gravel, and soft lava, and there is, indeed, some doubt whether the bed rock was actually reached. A small pump elevates the water from this well to a tank from which the settlement is supplied. The well has yielded about 200,000 gallons a day (0.31 cubic foot per second) continuously. The water contains from 50 to 86 grains of salt per gallon. A sample on May 4 gave 83 gains; on June 11, 80 grains.

The three upper wells.—These are located on the west side of the gulch, 1,000 feet above the main pumping station and at elevations of 50, 60, and 63 feet. The depth of all of them is about 60 feet, water standing at sea level and containing 74 grains of salt per gallon. Except for a few feet of soil the wells are in lava of varying hardness. These wells have not been tested at all as to their capacity, as their high salinity seemed discouraging.

The deep well.—This well is the most northerly of the long row near the main pumping station. It has a diameter of 12 inches. The total depth at end of May, when discontinued, was 500 feet. The mouth has an elevation of 35 feet. Below 15 feet of gravel followed 25 feet of hard lava, below which porous, ashy, and caving lava was met down to 110 feet; from here to 150 feet followed hard lava, and then a porous stratum down to 250 feet. Below 250 feet hard and soft lava alternate, no special record being kept. The first water at sea level contained 50 grains of salt per gallon; at 160 feet the well broke into salt water, which continued until the work was stopped.

The 12 wells for main pumping station.—All of these are arranged in a row parallel to the bluff, and well No. 7, counted from south to north, has an elevation of 31 feet above mean sea level; from this elevation the other wells differ but little. All of the wells are 60 feet deep, except No. 13, which was known as the "donkey-engine well,"

and which is 75 feet. As in all of the wells bored, the absence detailed and reliable record is noticeable. Wells Nos. 7 to 13 rea bed rock at a distance of from 15 to 26 feet, indicating a decided s southward. Below this only lava was met with, the hardness ch ing every 15 or 20 feet. In wells Nos. 2 to 6, inclusive, the bed was deeper, 26 feet below surface or more, and it is vaguely st that every well showed a different record. In all wells the wate found at about sea level or, at most, 1 foot above it. The water first struck contained from 20 to 40 grains of salt per gallon. V Nos. 1 to 12 were tested by pumping at the rate of 300,000 or 40 gallons in twenty-four hours (0.46 to 0.6184 cubic foot per second) each for a few hours, the maximum salinity being 40 grains. No. 13 was tested somewhat more severely, being pumped four at the rate of from 500,000 to 750,000 gallons per twenty-four h (0.77 to 1.16 cubic feet per second). April 5, 1899, a sample from well contained 11.5 grains of salt per gallon. Pumping at the tioned rate from May 10 to 13 increased the salinity rapidly t grains, and the last day it reached 83 grains.

After the erection of the 10,000,000-gallon (15.47 cubic feet per ond) steam pump to draw from wells Nos. 2 to 13, inclusive, the pu ing began in January, 1900. According to Mr. D. Center, at beginning of the pumping the water contained 50 grains of salt gallon. The pumps were started at 2,500,000 gallons (3.87 cubic per second), and after one week the salt had increased to 110 gr per gallon. After one month it had reached 200 grains and in M 400 grains, though when it went up to the latter figure both pu were running at a total rate of 5,000,000 gallons (7.74 cubic per second). According to Mr. Boller, the engineer in charge quantities drawn were larger and for a considerable time va between 4,000,000 and 5,000,000 gallons (6.19 and 7.74 cubic feet second).

When it became clear that continued pumping would not brin fresh water a series of tests were made to find out, if possible, which wells the salt water came, but the result seemed to ind that it was derived from all of them. Wells Nos. 2 to 6 seeme contain better water than the others, the salt amounting to only a 150 grains per gallon. The quantity of water was, however, sm and these wells were easily pumped dry. In whatever way the c wells were arranged the water reached from 270 to 485 grains.

During heavy pumping from wells Nos. 7 to 13 their water was lowered 1.5 or, at most, 2 feet.

Risdon wells.—These wells, so called because of the intentio erect a 20,000,000-gallon (30.94 cubic feet per second) Risdon p on them, are located just 1 mile east-southeast of the Kaunak wells described above, at the eastern end of the cane fields. T

wenty 12-inch wells 40 feet apart, located in three rows, which are 40 feet apart with a northeast direction parallel to the dry creek the mouth of which they are placed. They are bored at the foot low, rocky bluff, at the foot of which, 1,000 feet south of the , a strong spring appears. The most southerly well has a sur- elevation of 28 feet, and a shaft is sunk from the surface to a n of 20 feet, the well being bored 40 feet below the bottom of the . Well and shaft penetrated 10 feet of soil, 2 feet of bowlders, et of hard lava, 23 feet of porous lava, below which again comes lava. All of the other wells have similar records. Salinity, 70 ns; water level, 1 foot above sea level. The most southerly well pumped forty-eight hours at the rate of 750,000 gallons (1.16 c feet per second), after which the water contained 68 grains of per gallon and the water level was lowered 2 feet.

ne other wells were tested by pumping with the deep-well pump ne rate of 300,000 gallons (0.46 cubic foot per second), but only a short time. Maximum amount of salt, 74 grains per gallon.

KAWELA.

etween the Risdon wells and Onini station but little fresh water ears on the coast, but from the latter point to Kawela the indi- ions favor a larger supply. On the sandy flood plain of the wela the kulianas find all the water needed in shallow wells, the el standing 6 inches above sea level. The water contains 3 grains salt per gallon. During floods in the Kawela the ground water nds 1 or 2 feet higher than usual.

Up to June, 1900, 9 wells of an average depth of 55 feet had been red at Kawela, all of them along the foot of the lava slope from 00 to 4,000 feet east of the creek. A number of kulianas or small ldings, usually owned by natives, are located on the sandy plain of wela and extend nearly up to the foot of the bluff.

Well No. 1.—This 14-inch well, started 12 feet above mean sea level, 46 feet deep. The well passed through the following strata: Soil, 4 t; hard lava, 10 feet; soft porous lava, 34 feet; hard lava at bottom. good stream of water was met at 14 feet from surface. Water level nds 10 feet 9 inches below surface, giving the water level an eleva- n of 1 foot 3 inches above sea level. Water contains 15 grains of t per gallon. Pumped at rate of 1,000,000 gallons in twenty-four urs for twelve hours (1.55 cubic feet per second), the amount of salt e to 25 grains. Subsequently, at the same time as the heavy pump- g took place on well No. 3, this well was pumped for three weeks at rate of 1,250,000 gallons in twenty-four hours (1.93 cubic feet per ond), the amount of salt rising to only 37 grains.

Well No. 2.—This 14-inch well is 40 feet east of No. 1, at an eleva-

tion of 12 feet above mean sea level. It is 50 feet deep, and passes through the same rock as No. 1, except that bed rock is at the surface. Water was struck 10 feet below surface, and the level raised to 1 foot below surface (the only instance thus far noted of artesian pressure). On further boring, however, the water level sank to about 2 feet above sea level, showing that some very porous strata had been encountered. Water contained 18 grains of salt per gallon. Pumped at rate of 1,000,000 gallons in twenty-four hours for twelve hours (1.55 cubic feet per second), highest amount of salt was 25 grains per gallon.

Well No. 3.—This 14-inch well is 40 feet east of No. 2, at a surface elevation of 11 feet. The well is 56 feet deep and passes through 2-foot soil, a few feet of porous lava, and then pretty solid lava until 9 feet above bottom, when a porous stratum was met. Water was struck 5 feet below surface, but at 46 feet depth it was easily pumped dry at rate of 1,000,000 gallons per 24 hours (1.55 cubic feet per second). The well was then sunk 10 feet farther, when a large flow of water was encountered. This single well was pumped for thirty days, March 1–30, 1900, at rate of 2,500,000 gallons (3.87 cubic feet per second). The water level was lowered 8 feet and the salinity rose as follows:

Amount of salt in well No. 3.

	Grains per gallon.
March 2	19
March 7	33
March 16	32
March 20	42
March 24	55
March 28	62
March 30	64

On May 16 the water level stood 8 feet 9 inches below surface of ground, or 2 feet 3 inches above sea level.

Well No. 4.—This 14-inch well is 1,080 feet east of No. 3, at an altitude 17 feet above sea level. It is 58 feet deep and passes through the following strata: Soil and gravel 4 to 5 feet, hard lava to 17 feet below surface, where a heavy stream of water was encountered and the water level raised to 13 feet below the surface; then followed a soft streak for 12 to 14 feet, and hard lava was again encountered in the bottom of the hole.

After short pumping with centrifugal pump it was decided to open the water-bearing stratum met 17 feet below the surface.

A pit was excavated about 12 by 24 feet, the longer side being parallel to the coast. The western half was sunk to 8½ feet below the surface, and a double-action two-cylinder 14 by 15 by 10 Worthington pump (strokes 86 per minute) was placed at this level. The eastern half of the pit was sunk deeper. On May 10 it had penetrated 15 feet

of hard but porous and open lava agglomerate. The water level stood 14 feet below the surface while pumping at the rate of 2,500,000 gallons (3.87 cubic feet per second). The water level in the deep-bore hole No. 4, situated in the middle of the western end line of the pit, was 1 foot lower. On May 10 the water from pump contained 37.5 to 40 grains of salt per gallon. Pumping began May 8 at 9 a. m. and continued with some intermissions to June 25, when the pumps were removed to well No. 6.

On May 16 the pit was down to 16 feet from surface, while the water stood 14 feet below, and work was becoming difficult. Pumping at the same rate was continued, the water containing 46 grains of salt per gallon. The water could not be handled with the Worthington pump, so a small centrifugal pump was added. On May 28 both were running with a total capacity of 3,500,000 gallons (5.42 cubic feet per second). Water coming into the big pit on northeast side 5 feet below sea level contained 29.5 grains of salt per gallon, while the discharge from the main pipe ran 40.4 grains, but contained up to 60 or 70 grains after some hours of continuous pumping.

In the first days of June a 2,000,000 gallon (3.40 cubic feet per second) centrifugal pump was substituted for the smaller one and total rate of pumping increased to 4,000,000 or 4,500,000 gallons (6.19 to 6.96 cubic feet per second). The water was discharged into a flume and was conveyed to the pond near the eastern boundary of Kawela. Up to the end of May the 20-inch suction pipe had been allowed to remain in the bore hole drawing up salty water all the time, but then this pipe was first shortened and finally placed in the bottom of the pit. The total depth of the pit from surface of upper (north) side is 18½ feet. Tunnels were now started from the northeast and southwest corners of the pit. On June 8, 2 p. m., pumping 4,000,000 gallons continuously, the water in the northeast tunnel ran 40 grains of salt per gallon, while the water in the flume contained 90 grains. On June 11, pumping continued as before, keeping water within 16 feet of bottom, the heavy stream of water from northeast tunnel ran 35 grains of salt per gallon. Another heavy flow, pouring from the well hole, contained 78 grains. The water in the main discharge flume contained 64 grains; later in the day 82 grains. A big stream of salty water also poured out 1½ feet above bottom of pit in southeast corner; a less amount of same on south side of northeast tunnel but only at its mouth, and still another smaller flow near southwest corner of pit. It had now become apparent that salt water came in from the bore hole and from the south side of the pit near the bottom. A futile attempt was made to check the flow from the bore hole by piling bags filled with earth around it. A week later the well hole was filled with cement, but only to a depth of 20 feet below the bottom of the pit, total depth below it being 40 feet. The pumping was

continued at same rate and the water contained the amount of salt indicated in the following table:

Amount of salt in water from No. 4 well.

[Grains per gallon.]

Date.	Northeast tunnel.	Southwest tunnel.	Flume.	Southeast flow.
June 12	39	27	120	200
13	48	38		
14—9 a. m	48	38	198	341
12 noon	51	52		364
15—2 p. m	57	33		
4 p. m				430
19 [a]	56	65	127	
20—12 noon [b]			125	
4 p. m	45	65	150	285
21 [c]				
22—9 a. m [c]	52	68	110	168
4 p. m	65	48	150	283
23—9 a. m	49	60	111	
4 p. m	52	37	142	238
24 [d]	57	32		
25 [e]				

[a] Pumping stopped for two days.
[b] Running day time only.
[c] June 21 about same as June 20.
[d] No pumping.
[e] Irregular pumping.

All tunnel samples were taken at face.

On this day the tunnel had advanced 32 feet from the pit. The rock, which had been porous and soft, was becoming hard at face, and much water was coming in from the roof. The southwest tunnel had advanced 23 feet in porous rock, but the same was becoming hard, a good stream of water coming in from the floor.

An analysis of above data shows that the two tunnels furnished from 2,250,000 to 2,500,000 gallons (3.48 to 3.87 cubic feet per second) of water, containing on the average 50 grains of salt per gallon, while the southeast flow and the bore hole furnished from 2,000,000 to 2,250,000 gallons (3.10 to 3.48 cubic feet per second), containing from 200 to 400 grains of salt per gallon. Practically all of the salt water comes from these two sources. The rapid increase in salinity from the southeast flow and the bore hole shows that there are leaks in the rocks at these points in almost direct connection with the sea water, while the other parts of the pit had no such connections. It might well have been possible to isolate these sources of contamination.

Well No. 5.—This 14-inch well is located 226 feet east of No. 4, and is 75 feet deep. It passed through the following strata: Soil 3 feet, hard lava to 29 feet from surface, soft red lava tuff to 47 feet from surface, hard lava to 70 feet from surface, soft again from 70 to 75 feet. The water stood 9½ feet below the surface, or 2½ feet above sea level. On May 16 I measured water level to 9 feet 1½ inches below surface. Salinity, 35 grains. Pumped with centrifugal pump at rate *of 750,000 gallons* (*1.16* cubic feet per second) May 8 and 10, but not

ontinuously. On pumping the level immediately fell 2 feet 3 inches. lighest salinity, 35 grains.

Well No. 6.—This 14-inch well is located 255 feet west of well No. 4 nd is 60 feet deep. It passed through the following strata: Soil and ravel with bowlders, 40 feet, remainder lava, in part soft. Water ontains 25 grains of salt per gallon. Was pumped two days with ell pump (capacity, 300,000 gallons, or 0.46 cubic foot per second). Water stands normally 15 feet 6 inches below surface. Pumped also ntermittently from June 11 to June 16 at rate of from 500,000 to 50,000 gallons (0.77 to 1.32 cubic feet per second), the water level nly being lowered 3 to 4 inches. On June 16 the water contained 1 grains of salt.

Well No. 7.—This 14-inch well is located 240 feet west of No. 6, and s 59 feet deep. It passed through soil and gravel 30 to 35 feet, below his lava of varying hardness. There were no pumping tests up to une 30 on account of lack of available pumps.

Well No. 8.—This 14-inch well is 240 feet west of No. 7 and has a otal depth of 58 feet. There have been no pumping tests.

Well No. 9.—This 14-inch well is 195 feet west of No. 1, at an elevation of 20 feet. Down to some feet below water level hard lava revails. The well was not finished by end of June. There are no pecial tests of water from the last three wells, but the amount of salt anges from about 25 to 35 grains per gallon.

On the west side of Kawela Gulch a shaft was sunk at an elevation f 30 feet in a small side gully. Water containing only 3 grains of alt per gallon was found somewhat above sea level. The water came n too fast for bailing, but no pumps being available nothing further as done at this locality.

Other wells.—Since the middle of May, 1900, a series of six shafts by 5 feet) have been sunk to sea level between the wells, but no umping has been done on these. It was proposed to extend a tunnel om well No. 4 to well No. 1, a little below sea level; this tunnel was grade toward No. 1, where a central pumping station was to be cated, and was to collect the upper stratum of the ground water, to hich that from the deeper strata down to 60 feet was to be added by umping from the wells. As it was shown, however, that tunneling nder existing circumstances was quite difficult at well No. 4, it was tended at the time of my departure from Molokai to substitute an en cut and trench for the tunnel.

THEORETICAL AMOUNT OF WATER AVAILABLE.

The rain falling on the island is disposed of in the three following ays: One relatively small part is evaporated from soil and from ants. A second and large part is absorbed by the soil and, connually moving, sinks down to the surface of permanent saturation, hich slopes gently *seaward;* all of this water finds its way to the *ore and must emerge from* the rocks at or about sea level. A third

part runs off in the living streams. On the north coast and in the summit region this amount reaches at least one-half of total rainfall, for the ground here contains much water and only slowly absorbs more. Over the south slope the run-off is very small, for the living streams are here largely absorbed before reaching the sea. The run-off of the total south slope is probably only 30 per cent of the total rainfall. It is greater at Kawela than at Kaunakakai.

Absolute data can not be obtained on account of lack of information as to rainfall; but, taking all conditions known on this and adjacent islands, the following approximate calculation may be made:

Total area of south slope from Meyers Creek to east boundary of Kawela is 54 square miles; average rainfall over this area is 4 feet per year; total annual rainfall over this area, 6,048,000,000 cubic feet, or 45,358,000,000 gallons, or 126,000,000 gallons per twenty-four hours (194.95 cubic feet per second); evaporation, 26,000,000 to 36,000,000 gallons (40.23 to 55.70 cubic feet per second); run off, 20,000,000 to 30,000,000 gallons (30.94 to 46.42 cubic feet per second); ground water, 60,000,000 to 80,000,000 gallons (92.83 to 123.78 cubic feet per second). Of this amount it was proposed to secure nearly one-half, or 30,000,000 gallons (46.42 cubic feet per second), at one place near Kaunakakai, which clearly would be impossible.

The ground water available from one-half mile west to 1 mile east of Kaunakakai and from the coast to the summit, including the drainage of Kaunakakai and small gulches to the east, may be roughly calculated as follows:

Area, 36,000 by 12,000 feet; average rainfall over whole area, 4 feet; total amount of water, 1,728,000,000 cubic feet, or 13,000,000,000 gallons per year, or 36,000,000 gallons in twenty-four hours (55.70 cubic feet per second); evaporation, 8,000,000 to 12,000,000 gallons (12.38 to 18.57 cubic feet per second); run off, 5,000,000 to 10,000,000 gallons (7.74 to 15.47 cubic feet per second); available for ground-water circulation, 14,000,000 to 23,000,000 gallons in 24 hours (21.66 to 35.59 cubic feet per second), which amount must emerge along the coast. It is thus seen that a considerable amount of water is available, though it is probably distributed pretty evenly over the distance, and its long passage through the rocks has rendered it salty. The fact that for a whole year 1,000,000 gallons (1.55 cubic feet per second) has been pumped from the cane-field well goes to prove that there must be a fair amount available along the coast.

A considerable amount of ground water is available at Kawela Gulch. Assuming a drainage area of 24,000 by 12,000 feet for the Kawela property and an average rainfall of 5 feet, for the rainfall is decidedly more than over the Kaunakakai drainage area, we obtain 1,440,000,000 cubic feet, or 10,800,000,000 gallons a year, or 30,000,000 gallons a day (46.42 cubic feet per second). Assuming 6,000,000 to 10,000,000 gallons (9.28 to 15.47 cubic feet per second) evaporation, 4,000,000 (6.19 cubic feet per second) run off, 16,000,000 to

20,000,000 (24.76 to 30.94 cubic feet per second) remain for the ground water that may be considered available near Kawela Gulch. While the total supply is not much larger than at Kaunakakai it is more concentrated and the water is less saline, the normal flow averaging about 35 grains, the flood water on top sometimes going as low as 3 grains.

These calculations of the relative quantities at Kaunakakai and Kawela may not quite express the actual conditions, for from the geologic structure it seems very probable that a large part of the ground water from the headwaters of Kaunakakai Gulch finds its way down to Kawela, thus considerably increasing the amount available there.

The ground water probably available at Kamalo may be roughly estimated as follows:

Assuming a drainage area of 20,000 by 10,000 feet and an average precipitation of 5 feet, we obtain a total of 7,500,000,000 gallons a year or 21,000,000 gallons a day (32.49 cubic feet per second), of which the larger part, perhaps 12,000,000 or 15,000,000 (18.57 to 23.21 cubic feet per second), should be available at or near the mouth of the gulches. Several more favorable locations may be selected between Kamalo and Mapulehu which should aggregate 10,000,000 gallons (15.47 cubic feet per second).

Considering now the high region above with a view to ascertaining how much water may be available for an irrigation system collecting the run-off of the area from the head of Kawela to Waihanau, we may approximately calculate as follows:

Total area involved, 32,000 by 4,000 feet; average rainfall, approximately, 8 feet; total amount of water, 1,024 cubic feet or 7,680,000,000 gallons a year, equivalent to 21,300,000 gallons a day (32.96 cubic feet per second). The run-off, which is here at least 50 per cent of total precipitation, would be 10,500,000 gallons (16.25 cubic feet per second).

The drainage area of the upper Waihanau is 10,000 by 2,500 feet, over which a rainfall of 8 feet may be expected. Total water, 200,000,000 cubic feet, or 1,500,000 gallons per annum; it is proposed to collect the entire run-off of this; the amount estimated by stream measurements is 710,000,000, which is a little less than half of the total precipitation.

UTILIZATION OF THE WATER SUPPLY.

The principal problem on Molokai is how to obtain water for irrigation of the 14,000 acres of deep soil situated in the great gap. Another problem is how to obtain water for the irrigation of the smaller coast flats occurring at intervals from Palaau to Mapulehu.

According to the ordinary estimates of sugar planters, 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) are needed to irrigate 100 acres of sugar cane. In the opinion of many this is too much, but at that *rate* 14,000 acres would necessitate 140,000,000

gallons per twenty-four hours (216.61 cubic feet per second). Assuming 1,000 acres of coast flats, 10,000,000 gallons (15.47 cubic feet per second) more would be needed. It is evident that such an amount of water is not available on the island. A certain amount of water can, however, be obtained and it is of interest and importance to attempt to estimate this quantity. Sooner or later the welfare of the island may demand that all possible resources be made available. First of all, the running water at high elevations must be considered. In a few places, as at Kamalo, this water is carried down in steep-grade ditches to irrigate fields at the coast. This plan is probably impracticable in the long run, for these ditches will soon be washed out and there is great loss of water by absorption. If this plan is to be considered, it would be necessary to conduct the water in iron pipes, but the quantity in each place is usually small, so that it would also be an expensive undertaking for the results achieved. Another plan would be to collect the water of the upper region as far east as Kamalo and to carry it by a series of ditches to storage reservoirs above the cane lands. This would be more feasible and such a plan is considered in the following pages. The supply would entail small expense for maintenance. If cemented ditches were used in places the plant would be put on a permanent basis, necessitating no renewal every ten or fifteen years, as is the case with flumes. There is a further source of supply in the ground water along the coast. This can be collected, carried by flumes or cemented ditches to a point near the cane lands, whence it would have to be raised 400 feet by means of a force pump. Few agricultural industries but sugar plantations could bear such a tax, but, as well known, there are many such high-power pumping plants in the islands, especially on Maui. The expense would be still further increased by the necessity of many well plants, for it is certain that no one place will supply a very great quantity of water. There is a possibility of using electric power, which may aid to solve the problem. At any rate, I think it certain that the coast flats could easily be irrigated from wells, which would not necessitate high pumping.

Another point to be considered is the salinity of the waters. The running streams are very pure, but all of the ground water is more or less contaminated by common salt or sodium chloride. There is less of this at Kawela and Kamalo and to the east, but west of Kawela the salinity increases and reaches 90 grains per gallon at Kaunakakai and Palaau. The danger point in using saline water for sugar plantations is stated to be about 100 grains per gallon. Above this the waters become undesirable and their application may spoil the lands, especially if they are low lying.

UTILIZATION OF THE RUNNING STREAMS.

The amount of water which yearly flows to the sea through Meyers, *Kaunakakai, and* Kawela gulches is not large, though the torrents are

violent while they last. To collect this amount at sea level would be difficult in many respects, and this plan is not to be recommended; nor will it be less difficult to collect the water from the streams while running at elevations of 500 to 1,000 feet. Flumes would be long and expensive, and the long seasons during which they must remain dry would necessarily soon destroy them.

The only place to economically collect the running water is near the summit region. Here the streams are more constant and less torrential; here, also, is the region of heaviest rainfall and largest relative drainage area. In their lower course most of the streams are in box canyons which can not collect a large amount of water.

It may be thought that flumes have been used too extensively in the scheme outlined below, and in some places where the soil is very light ditches may possibly be substituted, but the danger of losing water by leakage is great, though not so great as farther down the slope, and in installing the system tests and measurements should be constantly made to make sure that no avoidable losses take place. During the dry part of the season most of the streams will flow only a small amount, and a few will dry up altogether; there will be enough, however, to keep the flumes from drying and shrinking. It is probably not desirable to go beyond Kamalo Gulch for the purpose of collecting water for the region of the gap. Beyond this point the summit region is very precipitous and the expense of construction and maintenance would be very great.

The system of collection is combined with a system of storage by which part of the waters of the rainy season will be stored for summer use. A number of reservoir sites have been selected and surveyed which, it is believed, will be tight and satisfactory.

Referring to the data given above under "Running streams," the following amounts are believed to be available in the different gulches at elevations given below:

	210 days (Nov. 1–June 1).		60 days (June 1–Aug. 1).	
	Gallons per 24 hours.	Cubic feet per second.	Gallons in 24 hours.	Cubic feet per second.
Waihanau	3,250,000	5.02	1,000,000	1.55
Waialeia	300,000	.46	100,000	.15
Waikolu	1,250,000	1.93	300,000	.46
Kahapakai	250,000	.39	150,000	.23
Mokamoka	200,000	.31	100,000	.15
Luahine Fork	200,000	.31	75,000	.12
Kamiloloa	275,000	.43	100,000	.15
Makakupaia	425,000	.66	150,000	.23
West Fork Kawela	200,000	.31	50,000	.08
East Fork Kawela	1,200,000	1.86	300,000	.46
Total	7,550,000	11.68	2,325,000	3.58

This gives a total for two hundred and seventy days of 1,725,000,000 gallons (230,500,000 cubic feet). During the remaining months of the year there will be a varying flow less than 2,000,000 gallons (3.09 cubic feet per second), which may be considered to offset losses by leakage and evaporation. Assuming 500 acres to be irrigated with 5,000,000 gallons a day (7.74 cubic feet per second), or 1,825,000,000 gallons (244,000,000 cubic feet) a year, which amount certainly is ample, a storage capacity of about 577,000,000 gallons (77,000,000 cubic feet) is required in this case to supply about 480 acres with a steady flow of 4,800,000 gallons in twenty-four hours (7.43 cubic feet per second). During part of the winter months the full amount of water is not needed and consequently any increased storage capacity will increase the area which can be irrigated. The water is to be taken out as follows:

Waikolu.—Elevation of dam 3,600 feet; 4,500-foot flume, 2 by 1½ feet; grade 10 feet per mile; capacity 3,000,000 gallons (4.64 cubic feet per second); to cross gap at head of Makakupaia with 2,000 feet of 10-inch riveted pipe, and discharge in Kamiloloa. Probably too much loss of water would result by allowing water to run down into Makakupaia Fork.

Kawela.—Elevation of damming place 3,220 feet; 15,000 feet of flume to Makakupaia Fork; grade 10 feet per mile; capacity 8,000,000 gallons (12.38 cubic feet per second); size 2 by 3 feet; to dump water over edge of canyon into Makakupaia Fork; crosses Onini Gulch in siphon.

Makakupaia.—Elevation of dam 2,650 feet; 17,000 feet to Hunter's cabin; grade 10 feet per mile, dumping water in upper East Fork of Luahine Gulch at elevation of 2,600 feet; capacity 16,000,000 gallons (24.76 cubic feet per second); size 3 by 4 feet; crossing tributary gulches of Kaunakakai Gulch in siphons and receiving tributary flume from Kamiloloa and Waikolu.

Kamiloloa.—Elevation of dam 3,050 feet; 4,500 feet of flume, 2 by 2½ feet carrying; capacity 5,000,000 gallons (7.74 cubic feet per second); sharp grade,

Luahine Fork.—The water from the Makakupaia ditch is dumped into East Fork of Luahine. The latter is dammed at an elevation of 2,350 feet; 9,500 feet of flume to Kahapakai; size 3 by 4 feet; grade 20 feet per mile; capacity 20,000,000 gallons (30.94 cubic feet per second); crossing Mokamoka Fork and West Fork Luahine in siphons, receiving their flows in 2 by 1 foot tributary flumes; dumps at an elevation of 2,300 feet in Kahapakai.

Waialeia.—Damming place at an elevation of 2,760 feet; 4,000-foot flume 14 by 12 inches; 10-foot grade; dumping into Waihanau; capacity 1,000,000 gallons (1.55 cubic feet per second).

Waihanau.—Damming place at an elevation of 2,046 feet; 4,200-foot flume, 2½ by 3 feet; grade 10 feet per mile; capacity 10,000,000 gallons

(15.47 cubic feet per second); 400 feet of tunnel; dumping water into Kahapakai.

Kahapakai.—Damming place at an elevation of 2,000 feet; 3,000-foot flume, 3½ by 4 feet; capacity 30,000,000 gallons (46.42 cubic feet per second); grade 20 feet per mile; dumping into reservoir No. 1 at Meyers Lake.

From reservoir No. 1 there are several ways by which the water can be conducted down to the lower reservoir sites. The simplest would be to let it run down Meyers Creek to an elevation of 1,100 feet, whence it could be taken to the reservoirs in a ditch. This will, however, almost certainly cause large losses, which can not be afforded. A better plan would probably be to let it down to an elevation of 1,600 feet—that is, 300 feet below the reservoir—whence it can be conducted by a sharp-grade flume across the gap below the reservoir and thence to the head of the flat gulch in which the big reservoirs are located. This gulch, it is believed, is fairly tight; at any rate it is worth trying. Should the losses in this gulch be too large it will be necessary to construct a series of ditches at low grade connected with sharp drops which will conduct the water down to the reservoirs. It should be mentioned that all parts of the system are easily accessible. A wagon road extends from Kaunakakai to the gap at Kaohu station above reservoir No. 1; another road is built from Kaunakakai to Waikolu. Still another can be constructed at very slight cost from Kaunakakai by way of Makakupaia station to the headwaters of Makakupaia, and to the edge of the canyon above the West Fork of Kawela. In places the flumes will be difficult to build, but there do not appear to be serious obstacles in any place.

The required storage capacity, 577,000,000 gallons (77,000,000 cubic feet), is to be obtained as follows:

The highest reservoir is known as Meyers Lake, a small natural pond dammed to some extent by Mr. Meyer. It consists of two basins which can readily be dammed to contain 160,000,000 gallons (21,000,000 cubic feet). The elevation is about 1,900 feet. The site is excellent; the ground is evidently very tight and evaporation slight. Considerable wave action may be expected and the main dam must be riprapped and protected by a break water of logs. Abundant and excellent dam material, clayey, decomposed soil close at hand. Large quantities may be loosened by bank blasting. Two different schemes are proposed; if only the lower basin which drains towards Meyers Gulch is utilized, the capacity will be reduced to 91,000,000 gallons (12,000,000 cubic feet). If both basins are utilized they must be connected by a drain or siphon. The upper basin drains toward the north by means of a narrow cut which must be filled by a dam.

Dam No. 2 and No. 3 are natural basins at elevations of about 900 to 1,000 feet, apparently entirely tight and in their present state ready to receive water. They are situated about 2 miles west-north-

west of Meyer's ranch on the broad grassy ridge south of Eleuweuwe Point. They must be emptied by means of siphon pipes or drain tunnels.

Most of the gulches and creeks of the island have a very steep grade. Among the exceptions to this rule are the three gulches discharging on the north coast over the 1,000-foot pali, 2 or 3 miles north of Middle Hill. The water courses are from 2 to 4 miles long and meander with relatively low grade through the grassy rolling country here continuing out to the very edge of the pali. Their valleys are from about 100 feet deep up to 800 feet wide; their sides, as a rule grassy and covered by clayey soil. Receiving but little precipitation they contain but little water, even during heavy rains and are thus excellently adapted for storage. Water can be stored in all three at elevation of from 800 to 1,000 feet. The most southerly of these creeks, flowing just south of Eleuweuwe Point, is best adapted for reservoir sites. There is no difficulty in carrying the stored water out from the reservoirs and down toward the cane lands. Four reservoirs were planned on this creek, though one of these, No. 2, may be dispensed with as the desired capacity is obtained without it. The dams must be carefully constructed of the abundantly available clayey soil, and I believe that the reservoirs will be found water-tight. They are calculated to 10 feet on top with a slope of 3:1 on both sides. The surveys for these dams were made for me by Mr. E. Pope, at that time one of the surveyors of the American Sugar Company.

List of reservoirs.

No.	Capacity.		Height of dam.
	Gallons.	*Cubic feet.*	*Feet.*
1 (Meyers Lake)	160,000,000	21,389,000	[illegible]
2	62,000,000	8,288,000	(a)
3	73,000,000	9,758,500	(a)
4	117,000,000	15,640,500	[illegible]
5	138,000,000	18,448,000	[illegible]
6	189,000,000	25,266,000	[illegible]
7	100,000,000	13,368,000	[illegible]
Total	839,000,000	112,158,000	

a Natural basin.

From the reservoirs at an elevation of 800 feet the water is easily conducted by ditches and drops in shallow ravines to an elevation of 450 feet, the height of the gap, whence it can be applied to any part of the cane lands desired. The distance from the reservoirs to the cane lands is from 2 to 4 miles. It is easily understood that it is not necessary to construct this whole system outlined above at once. The Waihanau, Waialeia, Kahapahai may be first utilized together with reservoirs No. 1 and No. 2 or No. 7. The results of this system which will irrigate at least 175 acres, will indicate the success to be *expected from the* installation of the whole system.

In conclusion it may be estimated that collecting and storing the running streams as outlined above will cost about $120,000 and the water collected amounts to a steady supply of nearly 5,000,000 gallons a day (7.74 cubic feet per second) during the whole year. The utilization of this water will interfere but little with the supply to be expected from pumps at sea level.

If it were found practicable to use the lands for cultivation of fruit trees and vines, this quantity of water—5,000,000 gallons in twenty-four hours (7.74 cubic feet per second)—would easily be sufficient to irrigate 1,000 acres. In view of the strong winds prevalent over the area containing good soil such culture may, however, be difficult. Experiments in this direction would be desirable.

In order to develop the water supply by catching some of the underground flow which otherwise would come out at elevations lower than the point of collection, tunnels might be driven at Waihauau, Waialeia, and Waikolu into the hill perpendicularly to the direction of the drainage, just above the damming place and in both directions from the creek; it is rather probable that notable amounts will thus be collected by comparatively short tunnels, say 100 or 200 feet in length.

Similar tunnels at the places where Kawela and Makakupaia forks are caught are not advisable.

Wailau and Pelekunu.—Referring to previous pages, it is estimated that Wailau has a minimum flow of 8,000,000 gallons (12.38 cubic feet per second) and Pelekunu of 7,000,000 gallons (10.83 cubic feet per second), both at an elevation of 600 feet; but measurements during the driest time of the year are necessary to confirm these figures. Only the minimum supply can be considered, for the high-level irrigation system proposed above has exhausted the greater part of storage capacity available.

The utilization of the water supply of these streams involves (1) a high-level ditch reaching the cane lands at an elevation of 450 feet and (2) long tunnels to bring the water to the south side of the island, the northern coast being entirely impracticable. Both ditch and tunnel will be very expensive.

There are two possibilities: (1) Utilization of Wailau alone; (2) utilization of Pelekunu and Wailau.

By the utilization of Wailau alone 8,000,000 gallons (12.38 cubic feet per second) of water will be obtained, and to this must be added water which will be found in the tunnel. The latter quantity is very doubtful, but will probably amount to several million gallons. The tunnel will tap Wailau, West Fork, at an elevation of 670 feet. The water from the East Fork will be added by ditch across gap south of Puu o Wailau. Length of tunnel to point in the canyon 1¼ miles above Dr. Morritz's house at Mapulehu (elevation 660 feet), 12,800 feet. From Mapulehu to the cane fields there will be 17 miles of conduit and flume,

with many siphons, the latter causing considerable loss of grade. Elevation of flume at cane fields, 450 feet. The expense of this undertaking would probably exceed $400,000. But it should be remembered that there are many things which may cause increased expense. Among these are the possibility that the tunnel may partly or wholly need cementing in order to become tight. Further, that loose strata may be met, which may largely increase the expense. Further, the difficulty of working the tunnel from both ends on account of descending grade and large quantity of water probably met with. Lastly, the difficulty of landing coal and machinery at Wailau. Time needed, if only worked from one end, three years.

By the utilization of Pelekunu and Wailau 14,000,000 gallons (21.66 cubit feet per second) should be secured, besides the large flow which will almost certainly be met in the tunnels. Ditches and flumes must be correspondingly enlarged, and a tunnel 14,500 feet long driven from Pelekunu to convey the water after it is collected from the different branches. The expense would be at least $800,000.

By tunneling the range from Kawela to Pelekunu the long and difficult conduit from Mapulehu to Kawela would be avoided and there would be also considerable saving of grade. The tunnel from Wailau (elevation 650 feet) to Pelekunu (elevation 635 feet) would be 15,000 feet long, while the tunnel from Pelekunu (elevation 635 feet) to Kawela (elevation 610 feet) would be 26,500 feet. All of the previously stated objections apply with still greater force. The enterprise would consume several years and require at least $1,200,000.

In conclusion, I consider it feasible to bring the water from Wailau and Pelekunu to the cane fields, but do not believe that the enterprise would be a paying investment.

UTILIZATION OF THE GROUND WATER.

This plan contemplates the pumping of water from shallow wells at suitable places along the coast up to a low flume, say 50 to 75 feet above sea level, and the further raising of it up to a level of 300 to 500 feet by means of reciprocating pumps. Considering the conditions fully outlined above, it is clear that a large volume of water, say 30,000,000 gallons (46.42 cubic feet per second), is not obtainable in any one place. The only way is to utilize all the resources as far as possible and to collect the water wherever found. It is true that this may be somewhat more expensive than if the water were found in one place, but it is the only plan possible, except if the supply from Wailau and Pelekunu be used.

When the ground water is concentrated about sea level, trenches, pits, or tunnels may offer the best means of collecting the same, the trenches and tunnels as a matter of course being extended parallel to the shore. Even in this case difficulties may occur, for the heavy pumping necessary to prosecute the work is apt to bring in sea water,

and leaks may be found which will admit large quantities of the same. If the water is more evenly distributed through the strata down to 30 or 40 feet below sea level, or if the bulk of it is found at the latter depth, sinking and tunneling become impracticable, for if it is attempted to keep the workings dry, the sea water, being under heavy pressure, is almost sure to find its way in. In such case groups of 14-inch bore holes should be used, and even when the water occurs at sea level they may become preferable. In these porous rocks the capacity of a single bore hole may be comparatively great and amount up to 1,000,000 gallons in twenty-four hours. There is great temptation to overdraw the capacity of wells, and this has been done both at Kaunakakai and at Kawela. Just as soon as a steady increase in salinity is noted the quantity drawn must be decreased. In these rocks one well has a large suction area. If one well will give 1,000,000 gallons (1.55 cubit feet per second), 20 wells surrounding it, say at the corners of each 40 feet square, will probably give at most 3,000,000 to 4,000,000 gallons (4.64 to 6.19 cubic feet per second). While many of these conditions seem discouraging, it should be borne in mind that one single well, that at Kaunakakai, has for over one year furnished a steady flow of water with a salinity of 85–90 grains per gallon, and that many similar places can doubtless be found along the coast.

At Palaau.—According to the data given above (wells and springs) there is probably a considerable amount of ground water available at Palaau at a depth of about 80 feet—how much is difficult to say; there is at least 1,000,000 gallons, possibly as much as 3,000,000. The wells bored have not been adequately tested, and this should first of all be done with the well and shaft near the deep well. If this will yield a steady stream for about a month or two of from 750,000 to 1,000,000 gallons (1.16 to 1.55 cubic feet per second) in dry season, I recommend that two or three more wells be sunk parallel to the coast, about 40 feet apart. If it should be found that these would yield 2,000,000 or 2,500,000 gallons (3.09 to 3.87 cubic feet per second) of water containing less than 100 grains of salt per gallon, this should be utilized to irrigate the bottom lands at Palaau, as well as part of the slopes above, which, though rocky, can be cleared and planted. About 1 mile of small flume will be needed. If the water is elevated to 100 feet by a reciprocating pump driven by electricity, it would require 44 horsepower, or 52 horsepower delivered at the motor. The salinity would be high—i. e., about 90 grains per gallon—and this may in the long run interfere with its use on the lowlands.

Cocoanut grove wells.—The 60-foot well at this place should be tested, which has not been done up to date. Should it be found that this well, with or without adjacent pit, will furnish 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) of salinity of 100 grains, this water may be used to irrigate the bottom lands adjacent, amount-

ing to 150 acres, less water being needed on these low-lying lands than on the higher ground. This would require 8 theoretical horsepower, or 10 delivered at the motor if electric power be used. Should the water prove too salt, water from Kaunakakai must be used.

Kaunakakai.—One well at Kaunakakai is clearly proved to be able to deliver a steady stream of 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second). It is probable that 2,000,000 gallons (3.09 cubic feet per second) more may be obtained from shallow wells to sea level between this well and the so-called Risdon wells, 1 mile eastward.

Risdon wells.—These 20 wells have never been adequately tested, and their capacity is in doubt. Such incomplete tests as have been made are encouraging, and the conditions seem to indicate that they may furnish 2,000,000 gallons of water (3.09 cubic feet per second) at 80 grains of salinity. The water is contained in a well-defined stratum of porous rock from 9 feet to 34 feet below sea level.

Kawela.—Between Risdon station and the west boundary of Kawela the ground water does not appear along the coast in notable quantities, and the prospect of obtaining water from wells is not encouraging. But one-fourth of a mile east of Onini station very large springs appear on the beach, and I believe that there is 2,000,000 gallons (3.09 cubic feet per second) of ground water available at this place. The wells should be sunk at the foot of the bluff, just east of the rock point which extends to the sea. Preliminary exploration by means of pits or shafts would be necessary to decide at what level the water will be found; possibly most of it is held above sea level, but this is a point which can not be decided at present.

On the west side of Kawela Gulch for a distance of 2,000 feet from the creek a considerable amount of water is probably available. I think 3,000,000 gallons (4.64 cubic feet per second) can be secured here, but whether at sea level or 30 or 40 feet below it is impossible to say at present.

The flood plain of Kawela Gulch at present contains much water in its gravelly bed, but this amount will probably be notably diminished by the diversion of its headwaters into the irrigation system as proposed above. Nearly all of the recent well boring and pumping has been done on the east side of Kawela Gulch. The total quantity of water proved seems to be 4,500,000 gallons (6.96 cubic feet per second). Of this, 2,000,000 gallons (3.09 cubic feet per second) of 40 grains salinity have been shown to be available at wells Nos. 1, 2, and 3; 2,500,000 gallons (3.87 cubic feet per second) of 60 grains salinity may be considered proved at well No. 4, with its pit and tunnels, if the flow of salt water is shut off, which probably can be done by filling the salty bore hole with cement and constructing a cement wall around the leak in the southeast corner of the pit (see p. 44).

Tunneling at about 4 feet below water level has proved a difficult undertaking, and will become more so in the loose gravelly material which will be encountered near wells Nos. 6, 7, and 8. It would probably be better to run an open cut 6 feet wide in the bottom and 4 feet below water level in a line of about 15 feet south of the wells, thus collecting all of the ground water available at sea level into one central station, whence the water could be pumped. But to this must be added such amounts of the ground water as is stored in lower strata, as, for instance, 55 feet below the surface at well No. 3. This deeper water may be secured by connecting the bore holes with the main cut at its level—i. e., 4 feet below the sea level—but each bore hole must first be very carefully tested as to capacity and lowering of water level. If necessary, the open cut must be extended west of well No. 1, and a tunnel run through the bluff of well No. 9. It is almost impossible to outline a plan which in its details can be strictly adhered to, for the conditions change almost from day to day and the work requires the personal supervision of a very skilled and experienced engineer. In conclusion, it is believed that 10,000,000 gallons (15.47 cubic feet per second) may be expected at Kawela, east of the creek, and 3,000,000 gallons (4.64 cubic feet per second) west of the same. At Kamalo a quantity of water almost equal to that at Kawela may be expected, and a few million gallons may doubtless be obtained at intervals between Kamalo and Mapulehu.

To collect these waters will doubtless prove an expensive undertaking, owing to the many small pumping stations. Should it be desired to pump a smaller quantity for purposes of irrigation along the coast, some of the small streams at high elevations could be used to generate electric power to drive the pumps below.

Recapitulation.—While the estimate of waters available below the surface is necessarily very uncertain and difficult, I should place the probable amounts as follows:

Probable amount of water available.

	Million gallons per 24 hours.	Cubic feet per second.
Palaau	3	4.64
Cocoanut grove wells	1.5	2.32
Kaunakakai	3	4.64
Risdon wells	2	3.09
Onini Station	2	3.09
Kawela (west)	3	4.64
Kawela (east)	10	15.47
High-level irrigation system	4.8	7.43
Total	29.3	45.32

ELECTRIC POWER AVAILABLE.

As stated before, the irrigation system from the running streams outlined above should furnish at an elevation of 800 feet a steady supply of 4,800,000 gallons a day (7.43 cubic feet per second), or 3,333 gallons a minute. If the water is applied below 425 feet on the south slope of the gap, 375 feet of fall will be available, giving a theoretical horsepower of 314, which if converted into electrical power by means of Pelton wheel and dynamo and transmitted with high potential to Kawela should be sufficient to raise 13,000,000 gallons 66 feet; length of pressure pipe, 15,000 feet; length of transmission to Kawela, 10 miles. The greatest item of cost is the pressure pipe, which should be 14 inches in diameter, riveted, and of wrought iron, and which would not cost less than $50,000. The transmission would offer no difficulties, nor would the loss in transmission with high voltage be large. The great cost of pressure pipe diminishes the value of this proposition. More electric power could be obtained by utilizing the upper reservoir, which has a capacity of 160,000,000 gallons (247.56 cubic feet per second). Quantity of water available, 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second), or 700 gallons per minute; fall available, 700 feet; total theoretical horsepower available, 123; horsepower available at pumps 5 to 10 miles distant, 75. Pressure pipe from reservoir to power station in Meyers Gulch, at elevation of 1,100 feet, would be 10,000 feet long; diameter of 8 inches should be sufficient. Here, again, the pressure pipe forms the principal item of cost, being not less than $15,000.

This proposition is more favorable, but still very expensive in comparison with the advantages obtained. On the whole, it seems more advisable to depend upon steam for motive power.

Electric power from Pelekunu, Wailau, and Halawa.—According to a preliminary report by Mr. M. M. O'Shaughnessy, dated December 5, 1899, the following approximate power could be generated by utilizing these streams:

Stream.	Normal flow (gallons per 24 hours).	Cubic feet per second.	Fall available for power	Horsepower (theoretical).
Halawa	5,000,000	7.74	300	263
Wailau	10,000,000	15.47	400	701
Pelekunu	5,000,000	7.74	200	210
Waikolu	3,850,000	5.96		

INDEX.

	Page.
ıral land, location and area of	19
occurrence and features of	10, 11
ll, features of	38
trees, occurrence and use of	20
T., examination of soil by	20
n Sugar Company, lands controlled by	25
borod by	40–43
the island	9
, wild, occurrence of	23, 30, 32, 35
ows, plates showing	10, 14
a grass, pasture lands covered by	
ariety of	21
rees, occurrence of	21
ree, occurrence and character of	21
lamage to forest by	23–24
D., information furnished by, as to amount of salt in well water	42
ive to flow of Waihanau and Waialeia rivers	31
n, occurrence of	22
character of	16–18
it grove, location of	20–25
near, character of	20
gs at	28–29
s at	39–40, 57–58
ultivation of	19, 21
efs, occurrence of	9, 15–16
nd, occurrence of	16
ion, old, evidences of	25
D., quoted on origin of precipices in Hawaiian group	13
mage to forests by	23, 24
occurrences of	16
s, occurrence and character of	22–32
power, amount available and cost of	60
tion, amount of	48
abandoned	25
f the island	24
ccurrence of	21, 22, 32
damage to, by grazing of cattle	23
y of	22, 23–24
ease of, causes of	23–24
tion and character of	21–23
ervation of, suggestions relative to	24
arity of occurrence of	16
of the island	12–15
nia, occurrence of	22
lamage to forests by	23
, kinds of	21
water, utilization of	56–60
Guavas, wild, occurrence of	21, 22
Halawa River, drainage area and flow of	33
electric power from	60
features of	12
Haleakala, view obtained of	22
Hau bushes, occurrence of	21
Hawaiian Islands, rocks in, recognized by petrographers	14
Hitchcock, C. H., cited on topography of Oahu	13
Honolulu, rainfall at	17
Ioli well, features of	38
Irrigation from wells	26
Kahapakai Fork, flow of	34
proposed dam on, features of	53
Kalamaula, wells on, features of	39–40
Kalaupapa Peninsula, area and elevation of	11
features of	13–14
Kaluakoi, area and topography of	10
character of soil of	19
wells of	37–38
Kamakaipo, wells at	38
Kamakou, elevation of	10
Kamalo, soil at	20
Kamalo Gulch, features of	37
view of	12
Kamalo Sugar Company, lands controlled by	26
Kamiloloa Gulch, proposed dam in, features of	52
Kaunakakai, boring for water at, proposed	25–26
cocoanut grove near	20
rainfall at	16–17
soil near, character of	20
well at, flow of	58
Kaunakakai Gulch, features of	35–36
wells in	40–43
Kawela, sandy soil at	20
Kawela Gulch, features of	36–37
ground water near	58–59
proposed dam in, features of	52
springs east of	29
view of mouth of	10
wells in	26, 43–47
Koa tree, occurrence and character of	22
Kolo well, features of	38
Kolo windmill, view of south coast at	10
Kukui tree, occurrence and character of	21, 22, 23, 32, 34
Lahale tree, occurrence and features of	20
Lands, agricultural, location and area of	19

	Page.
Lands, pasture, character of	21
Lantania, thickets of	20
Lava bowlders, extent of zone of	21
Lehua tree, decay of, causes of	23
occurrence and character of	22, 32
Leper settlement, area and population of	25
features of	21
Luahine Fork, proposed dam on, features of	52
Makakupaia Fork, proposed dam on, features of	52
Manania, pasture lands covered by	21
Map of the island	9
Mapeluhu, rainfall at	16
Maui, view obtained of volcano on	22–23
Mauna Loa, well near, features of	38
Meyers Gulch, drainage area of	33
volume of flow in	34
wells in, features of	39
Meyers Lake, features of	53
Meyers ranch, location of	25
rainfall at	17–18
springs on	29–30
Mokamoka Fork, character and flow of	34–35
Molokai ranch, rainfall at	17
water supply of	30
Molokai Ranch Company, lands controlled by	25
Momomie well, features of	37–38
Morritz, Dr., cited on rainfall on the island	16
Mountain apple, occurrence of	22, 32
Naiwa, wells on, features of	39
Newell, F. H., letter of transmittal by	7
Ohia tree, occurrence of	22
Olivine-diabase rock, occurrence of	14
Onini, springs near	58
Onini Gulch, character of	36
Orange, wild, occurrence of	22
O'Shaughnessy, M. M., report by, on generation of power	60
Palaau, cane land near	19
ground water available at	57
rainfall at	17
sediment land east of	20
springs at, features of	28
wells at, features of	38–39
Papaia trees, cultivation of	21
Papohaku, algaroba groves at	20
wells near	38
Pasture lands, character of	21
Pele grass, pasture lands covered with	21
Pelekunu River, character and flow of	32
electric power from	60
features of	11
flow of	55
rainfall on headwaters of	18
Pineapples, abandoned plantations of	25
Pope, E., surveys for dams made by	54
Population of the island	9, 25
Precipitation. *See* Rainfall.	
Pulu ferns, occurrence of	22
Puu o Kaiaka, well near	38
Rainfall, amount of	16–18, 48, 49
Rainfall, average annual	
disposition of	
Reefs, coral, occurrence of	9, 15–
Reservoirs, proposed sites for, features of	52–
Residual soils, character of	
Rice, cultivation of	
Risdon wells, features of	
location and features of	42–
Rocks, character of	14–
Run-off, amount of	48,
Salinity of the ground water, consideration of	
reference to	27,
Sand, coral, occurrence of	
Scenery of northeast coast, reference to	
Sedimentary soils, character of	
Soils, character of	18–
Springs, occurrence and features of	28–
high-level, occurrence and character of	29–
Storage of water, proposed	52–
Streams, cost of collecting and storing	55,
features of	11–12, 30–
utilization of	50–
Sugar cane, cultivation of, location and area of lands for	
irrigation of, amount of water required for	49–
Swamps, soil in, character of	19–
Taro, cultivation of	20, 23,
Temperature of the island	
Topography of the island	9–
Trails, references to	21,
Trees, kinds and characters of	21–
Ului ferns, occurrence of	
Vegitation on the island	20–
Waiakane, spring at	
well at, features of	
Waialeia River, drainage area and flow of	
proposed dam on, features of	
Waieli, well near	
Waihanau River, drainage area and flow of	
proposed dam on, features of	52–
Waikolu River, drainage area and flow of	31–
flow of	
proposed dam on, features of	
rainfall on headwaters of	
Wailau, view of north coast from landing at	
Wailau River, character and flow of	11, 23,
electric power from	
flow of	
rainfall on headwaters of	
view of north coast at mouth of	
Water, salinity of, consideration of	
supply of, general principles governing	26–
theoretical amount of, available	47–
utilization of	49–
Wells of the island	37–
Wili-wili tree, occurrence and character of	
Winds, character of	

Water-Supply and Irrigation Paper No. 78

Series { B, Descriptive Geology, 29
{ O, Underground Waters, 20

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON

ARTESIAN BASINS

IN

SOUTHWESTERN IDAHO AND SOUTHEASTERN OREGON

BY

ISRAEL C. RUSSELL

WASHINGTON

GOVERNMENT PRINTING OFFICE

1903

CONTENTS.

Page.

ter of transmittal 7
oduction 9
ditions on which the flow of artesian wells depend 10
face indications of the presence of subsurface water under pressure 14
ks of the region examined 16
Sedimentary rocks 16
Igneous rocks 18
Volcanic rocks 18
Plutonic or deep-seated igneous rocks 21
ological structure 22
tesian basins 24
Lewis artesian basin 24
Springs 26
Mountain Home 26
Boise 27
Salmon River 27
Little Valley 27
Bruneau Valley 27
Walters Butte 27
Enterprise 27
Sands 27
Owyhee Canyon 28
Vale 28
Westfall 28
Beulah 29
Drilled wells 29
Boise 29
Bruneau Valley 30
Little Valley 31
Guffey 32
Central 32
Enterprise 33
Ontario 34
Vale 34
Summary 34
Eastward extension 37
Otis artesian basin 37
Harney artesian basin 38
Springs 39
Burns 39
Little Sage Hen Valley 39
Silver Lake 39
Harney Lake 39
Malheur Lake 39
Summary 39

Artesian basins—Continued. Page.
Harney artesian basin—Continued.
Drilled wells ... 40
Harney ... 40
Burns ... 41
Summary ... 41
Whitehorse artesian basin ... 43
Artesian wells in alluvial deposits ... 44
Size of drill holes, the casing of wells, etc ... 45
Preservation of well records ... 46
Laws ... 47
Literature ... 50
Index ... 53

ILLUSTRATIONS.

		Page.
PLATE	I. Map showing position of area under discussion	9
	II. Sketch map of portions of Oregon and Idaho, showing artesian basins	16
FIG.	1. Cross section of two dishes with sand between	11
	2. Ideal cross section of a typical artesian basin charged with water from above	11
	3. Ideal cross section of an artesian basin charged with water from below	13

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., December 2, 1902.

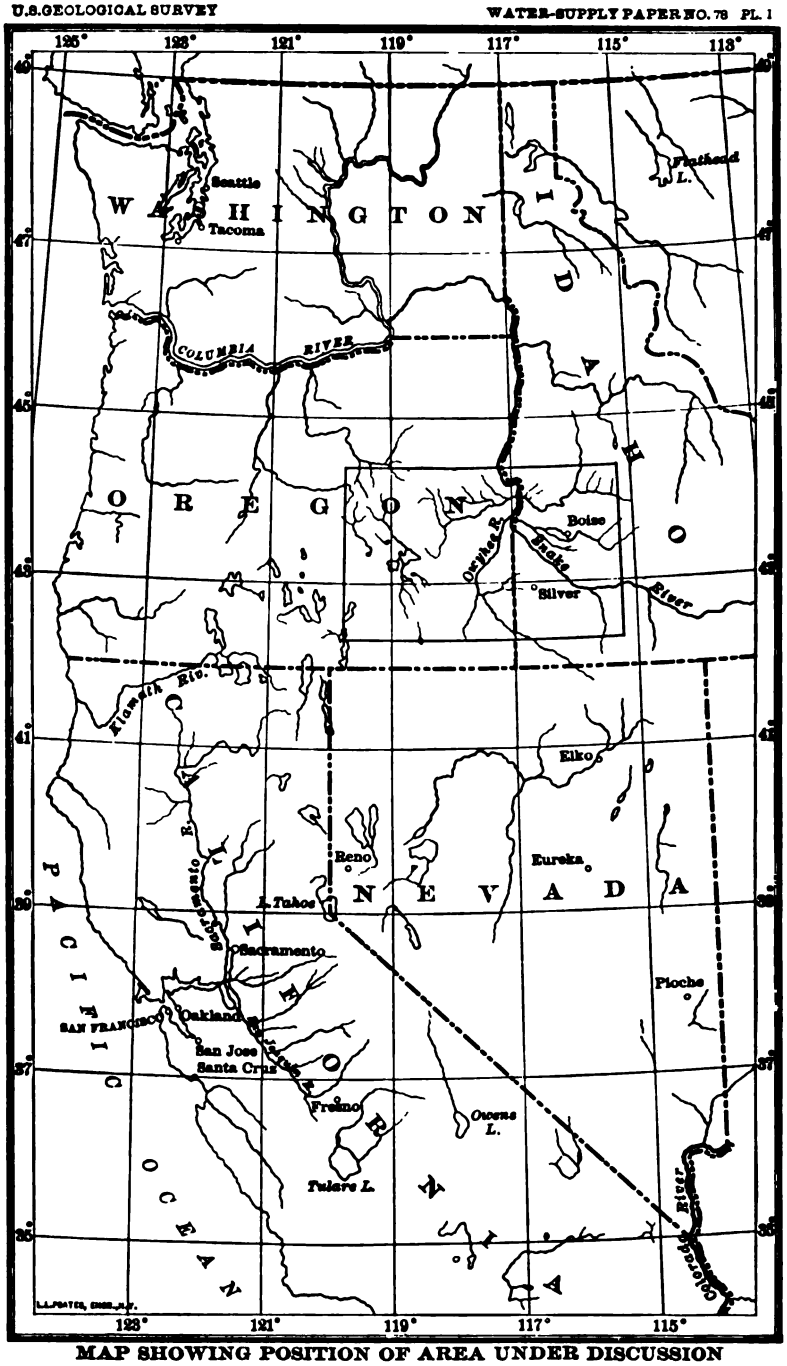
SIR: I have the honor to transmit herewith a manuscript prepared by Prof. Israel C. Russell, and to request that it be printed as one of the series of Water-Supply and Irrigation Papers. The paper relates to work carried on by Professor Russell during the summers of 1901 and 1902, and contains a description of the geologic structure of southwestern Idaho and southeastern Oregon, with special reference to the occurrence of underground waters. The artesian basins are described as far as these are known, and facts are assembled as to the probabilities of obtaining deep or flowing wells.

The information has particular value at this time, when great interest is being displayed in the reclamation of the arid lands. All facts which assist in procuring water are eagerly sought, and the data collected by Professor Russell are particularly important in the development of a large extent of vacant public land.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



MAP SHOWING POSITION OF AREA UNDER DISCUSSION

Scale

100 50 0 100 200 300 miles

PRELIMINARY REPORT ON ARTESIAN BASINS IN SOUTHWESTERN IDAHO AND SOUTHEASTERN OREGON.

By ISRAEL C. RUSSELL.

INTRODUCTION.

During the summer of 1901 I made a geological reconnaissance in southern Idaho which covered, in a general way, the region embraced in the Snake River Plains from the boundary between Ada and Elmore counties eastward to Blackfoot.[a] The studies thus begun were continued in the summer of 1902, when parts of Canyon and Owyhee counties, Idaho, and of Malheur and Harney counties, Oreg., were examined. The route traversed during the second reconnaissance followed Snake River from Guffey northwestward to the mouth of Owyhee River, in Idaho, and thence through Vale, Westfall, Beulah, Drewsey, Harney, Burns, Narrows, Diamond, Smith, Mule, Alvord Valley, Jordan Valley, etc., in Oregon, to Rockville, on the west border of Owyhee County, Idaho. From Rockville the return to Boise was by way of Caldwell and Nampa. The route followed was chosen for the purpose of passing through the greatest number of valleys where artesian conditions might most reasonably be expected to exist and where the largest areas of good land are available for agriculture.

Each of the journeys referred to above was a rapid reconnaissance, having for its principal object the discovery of localities where flowing water can be obtained by drilling wells. In addition to gathering facts bearing on the question of an artesian water supply, as much attention as the time available would permit was given to the study of the general geology of the country traversed, the surface water supply, soil conditions, etc. The results of my examinations may, then, be divided into two parts—namely, that pertaining directly to artesian basins and that relating to geological history, topographical development, etc. As the search for artesian basins, especially during the journey made in 1902, was far more successful than I had hoped, it

[a] A report on this reconnaissance, entitled Geology and Water Resources of the Snake River Plains of Idaho, has been published as Bulletin No. 199 by the United States Geological Survey. A copy of this report may be had without charge by applying to the Director of the United States Geological Survey, Washington, D. C.

seems advisable to present a preliminary report, with the view of giving early information concerning the artesian basins to the people living in the region examined and later to prepare a more definite record of the geological and geographical facts observed.

During the reconnaissance of 1901 it was found that the geological conditions in the Snake River Canyon from near Glenns Ferry westward to the boundary between Elmore and Ada counties and in Bruneau and Little valleys are such that a surface flow of water can reasonably be expected where the surface elevation is not too great if wells are drilled to the proper depth. The artesian basin crossed by the portion of Snake River just mentioned was for convenience named the Lewis artesian basin, but its extension west of the boundary between Elmore and Ada counties was not examined. The western portion of the basin was made the first subject of study during the following field season, and, as will be stated later, it was found to reach westward to beyond the Idaho-Oregon boundary.

The reconnaissance in southeastern Oregon showed that if wells are properly drilled, a surface flow of water may reasonably be expected in at least three separate valleys in addition to the basin which is crossed by Snake River. These are Otis Valley, situated about miles north of Drewsey; the broad valley in which Malheur and Harney lakes are situated, known in part as Harney Valley; and Whitehorse Valley, situated about 10 miles east of the higher portion of Stein Mountain. The basins in which these valleys are situated will be termed in this report the Otis artesian basin, the Harney artesian basin, and the Whitehorse artesian basin, respectively.

Before presenting the facts which are the basis of the conclusion that in each of the basins just named a surface flow of water can be had by drilling, it will, I think, be of assistance to review briefly the leading conditions governing the flow of artesian wells.

CONDITIONS ON WHICH THE FLOW OF ARTESIAN WELLS DEPENDS.

The term artesian well, as commonly employed, signifies a well which overflows upon the surface. The leading conditions favoring the rise and overflow of water from wells may perhaps be best indicated by describing the essential features of a typical artesian basin of the simplest character.

In what is properly termed an artesian basin, the layers of rock are bent downward, so as to resemble a pile of shallow plate-shaped dishes, placed one within another. One or more of the beds of rock is porous and allows water, supplied by rain on its upturned and exposed margin, to percolate into it. Above and below the water-charged layer are close-textured beds, like clay, which prevent the escape of the water in the bed between them. The leading condition

which characterize artesian basins will be reproduced on a small scale if one pan is placed within another, and the two are separated by a layer of sand, and the spaces between the sand grains are filled with water. If a hole is drilled in the bottom of the uppermost pan, water will rise from below and overflow until the level of the water in each pan is the same. This is illustrated by the following cross section (fig. 1), which represents two pans, with a layer of sand between them, as they would appear if cut across and one-half removed. The pans in such an experiment represent the compact or impervious layers, and the sand the porous or pervious bed, in an artesian basin.

FIG. 1.—Cross section of two dishes with layer of sand between; to illustrate the leading essential features of an artesian basin.

In the following diagram (fig. 2) an ideal cross section is presented through an artesian basin which may be assumed to be 50 or more miles in diameter. The rocks are in layers or strata, and their combined thickness, we will assume, is 1,000 feet. A cross section taken in any direction through the pile of saucer-shaped beds (as is the case with the experiment with the pans referred to above) would be essentially the same. In the diagram (fig. 2) B and C represent compact and impervious beds, such as clay or shale; and A represents a porous bed, such as sand, open-textured sandstone, or fissured and broken rock. The beds, it will be noted, are depressed in their central parts, but about their edges come to the surface. Under these conditions water falling as rain on the exposed margin of the pervious bed and the water from streams, etc., would percolate into it until it was water filled. If, now, a hole drilled in the central part of the

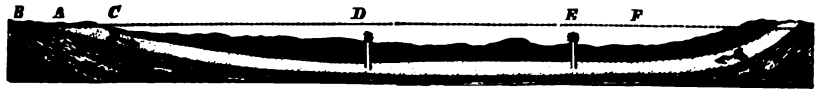


FIG. 2.—Ideal section illustrating the chief conditions requisite to artesian wells.

basin, as at D or E, reaches the pervious bed the pressure of water at a higher level will cause the water in the well to rise and overflow at the surface, and a flowing artesian well will result.

If, in the case just cited, no additional water should come to the exposed margin of the pervious bed, the well drilled at D or E would decrease in volume and finally cease to flow when the water in the porous bed, or so-called reservoir, was lowered so as to be on a level with the surface at the localities referred to. If, on the other hand, rain falls on the exposed margin of the pervious layer, or streams bring water to it, a continuous discharge from the well would result; as will be seen, one well in an artesian basin might be conspicuously

successful, while many wells might permit of such a freedom of escape of the water in a pervious bed as to practically ruin all of them.

In the illustration just presented, but one pervious bed was considered. In nature several such beds may be present in a single artesian basin, and several wells, drilled to different depths, might be successful, each well being supplied by a different pervious bed.

The height to which the water will rise above the surface opening of an artesian well depends on the height of the water in the raised border of the water-charged bed from which it derives its supply. For example, in fig. 2 the lowest point in the rim of the water-charged bed is at A, and if the pipe in the well drilled at D or E be carried up into the air and the end not closed, the water will rise in it until it reaches the level of A. The height to which the water will rise in an open tube attached to the surface opening of an artesian well is termed the artesian head. At all points within an artesian basin below the level of the artesian head water may be expected to rise to the surface and overflow when a well is drilled and properly cased. But if the surface of the ground is above the horizon of the outcrop of water-bearing bed, the pressure on the water will not be sufficient to force it to the surface, even if a drill hole is put down and properly cased. The height of the surface within an artesian basin may thus furnish the controlling condition on which success in searching for artesian water would depend. For this reason the pioneer well in an artesian basin should evidently be drilled at the lowest available locality in order to determine the artesian head. In making this test the bottom of the casing in the well should be just above the water-bearing stratum and securely packed on the outside so as to prevent leakage. If a well has a surface flow the height to which the water will rise above the ground may be learned by attaching a flexible hose pipe, or, in fact, any kind of a tube, to the upper end of the casing of the well and carrying it up a ladder or trestle until the water stands at the upper end, but does not overflow.[a] When two or more water-charged layers are present in an artesian basin, wells obtaining water from different layers may have different artesian heads.

Another necessary surface condition in reference to most artesian basins is that the margins of the porous beds shall rise to the surface and be exposed, so as to become charged with water from rain, melting snow, streams, etc. The amount of precipitation is also an important factor, especially in reference to the number of wells that may advantageously be put down in an artesian basin; but even in regions having an arid climate the porous beds beneath the surface so situated as to receive water at their edges, and from which its escape is prevented, will be found to be water charged.

As the pervious beds in an artesian basin commonly descend to

[a] Practical suggestions in this connection are presented in the papers No. 3 and No. 4 in the list at the end of this report.

considerable depth below the earth's surface, the water which escapes from them when drill holes are put down is usually warmer than the water in neighboring dug wells. The reason for this is that the temperature of the earth increases with depth below its surface, as is discussed below. The temperature of water in a pervious bed is therefore regulated by the depth of the bed below the surface, and several flowing wells drilled in the central part of a basin should yield water with essentially the same temperature.

In the case of artesian basins generally, the water supply is furnished by rain and streams and enters the pervious beds at their outcrops—that is, the water descends into the pervious beds from above. There are instances, however, in which the water rises from below. If a basin exists, as already explained, water may be supplied to the pervious beds either by the upward leakage of a lower pervious bed, or, as is illustrated in the following diagram, by fissures in the rocks beneath.

The water which rises through deep fissures in the earth's crust is commonly hot, and when it appears at the surface forms hot springs. In a case like that illustrated by fig. 3 the pervious bed is charged by

FIG. 3.—Ideal section of an artesian basin charged with water rising from below through a fissure.

water rising through the rocks beneath it, and artesian wells supplied by it would have a higher temperature than under normal conditions would be expected from their depth. More than this, several wells drilled in the central portion of a basin which is supplied in the manner just explained might vary greatly in temperature according to their distance from the subterranean source of supply, although deriving their water from the same pervious bed. The artesian head in the case just cited would depend on the height of the water stored in the pervious bed, but could not exceed the pressure on the incoming water from a deep source. Where there is a subterranean source of water supply for an artesian basin there is probably always an additional supply coming from above, so that both the pressure and temperature of the water obtained by drilling will be regulated by an adjustment between these two leading conditions.

There are other conditions than those just considered which permit a surface flow of water when wells are drilled, but so far as the artesian basins to be described later are concerned, it is unnecessary to consider them at this time.

Even when a well-defined artesian basin is present there may be qualifying or adverse conditions which will prevent a surface flow of

water where one might reasonably be expected. These "accidents," as they may perhaps be termed, are caused by the fact that sheets o rock which are open textured, and consequently pervious, in one por tion may become close textured and practically impervious in anothe portion. Also, an impervious bed may be fractured so as to allow the water to escape. In Idaho and Oregon the rocks which are bent so as to form basins are at times traversed by dikes; that is, more o less vertical sheets of rock formed by molten material forced upward into fissures from deep within the earth's crust, and cooling and hardening. There are still other locally adverse circumstances which may exist in even the best-defined artesian basins. These and other questions bearing on the success or failure of artesian wells have been discussed by several writers, and for a more complete and critical presentation of the subject than it is desirable to attempt at this time the reader is referred to the publications mentioned at the end of this report.

SURFACE INDICATIONS OF THE PRESENCE OF SUBSURFACE WATER UNDER PRESSURE.

The presence of artesian conditions is most frequently inferred from the structure of a basin, but confirmation of the supposition that water under pressure exists below the surface may frequently be had from the occurrence of warm springs. Such springs may also furnish evidence in reference to the depth to which a well should be drilled in order to penetrate the water-charged stratum.

The water which occurs in artesian basins has descended from the surface, and as the temperature of the earth increases with depth, the deeper the water has penetrated the rocks the higher will be its temperature. The increase in the temperature of the earth below a depth of about 50 feet in temperate regions is in general about 1° F. for each 60 feet, but there is considerable evidence for concluding that the rate of increase in southern Idaho and the adjacent part of Oregon is approximately 1° F. for each 45 feet in depth.[a] In temperate latitudes the increase in the temperature of the earth should be reckoned from a depth of 50 feet below the earth's surface, because the seasonal changes in temperature extend to that depth. At the horizon referred to there is a constant temperature which agrees with the mean annual temperature of the locality chosen. In the portions of Idaho and Oregon under consideration the mean annual temperature is approximately 50° F. In tropical countries the depth to which seasonal changes of temperature extend is less and in arctic regions much greater than that just stated. If, for example, a spring in the region referred to has a temperature of 65° F., or 15° above the temperatur

[a] The facts on which this conclusion is based are recorded in Bull. U. S. Geol. Survey No. 19 1902, pp. 173-174.

of the stratum of no seasonal variation, it would be safe to conclude that the water rises from a depth of at least 675 feet below that stratum or 725 feet below the surface. As the freedom of escape of the waters of springs is usually obstructed, some allowance must be made for its cooling as it rises, so that in the same case just cited 725 feet would indicate the minimum depth to which a drill hole would have to be extended with the hope of penetrating rocks in which water existed under sufficient pressure to cause it to rise to the surface.

In artesian basins there are apt to be localities where there is an escape of the water to the surface, so as to form springs. In such instances the springs usually flow throughout the year without appreciable changes in volume or in temperature, and the water is above the mean annual temperature of the locality where it reaches the surface. Where the structure of the rocks suggests that an artesian basin is present, the occurrence of warm springs within the basin is an assurance that water is present under sufficient pressure to force it to the surface in case wells are drilled. The warm springs referred to may be termed natural artesian wells, and their temperature indicates the depth of the water-charged bed below the surface, and the elevation of the locality where they occur gives a minimum measure of the height of the artesian head.

While warm springs (or those ranging in temperature from about 60° to 100° F.) situated within a region which has the structural features of an artesian basin may be taken as evidence of the presence of a water-charged layer which would supply flowing wells, a hot spring (or one having a temperature of more than 100°) is not so favorable an indication. Hot springs ordinarily rise from such a depth that even if they come from a well-defined water-charged layer it would be impracticable for most purposes for which artesian water is used to reach it by drilling. Although the conditions which lead to the occurrence of hot springs are not well understood, owing to the depth from which their waters rise, there are reasons for believing that they are frequently supplied by fissures that penetrate deep into the earth. The irregularities of fissures are such as to preclude prediction as to where they occur. In the case of every hot spring, however, there is a chance that if a well is drilled near it, even to a moderate depth, a flow of water will be secured, but in such instances the flow of water obtained should be classed as a "developed spring" rather than an artesian well. The fact, however, as previously explained, that water rising from a depth through fissures may charge the pervious beds in an artesian basin renders it evident that both warm and hot springs demand careful study in conducting a search for artesian water.

ROCKS OF THE REGION EXAMINED.

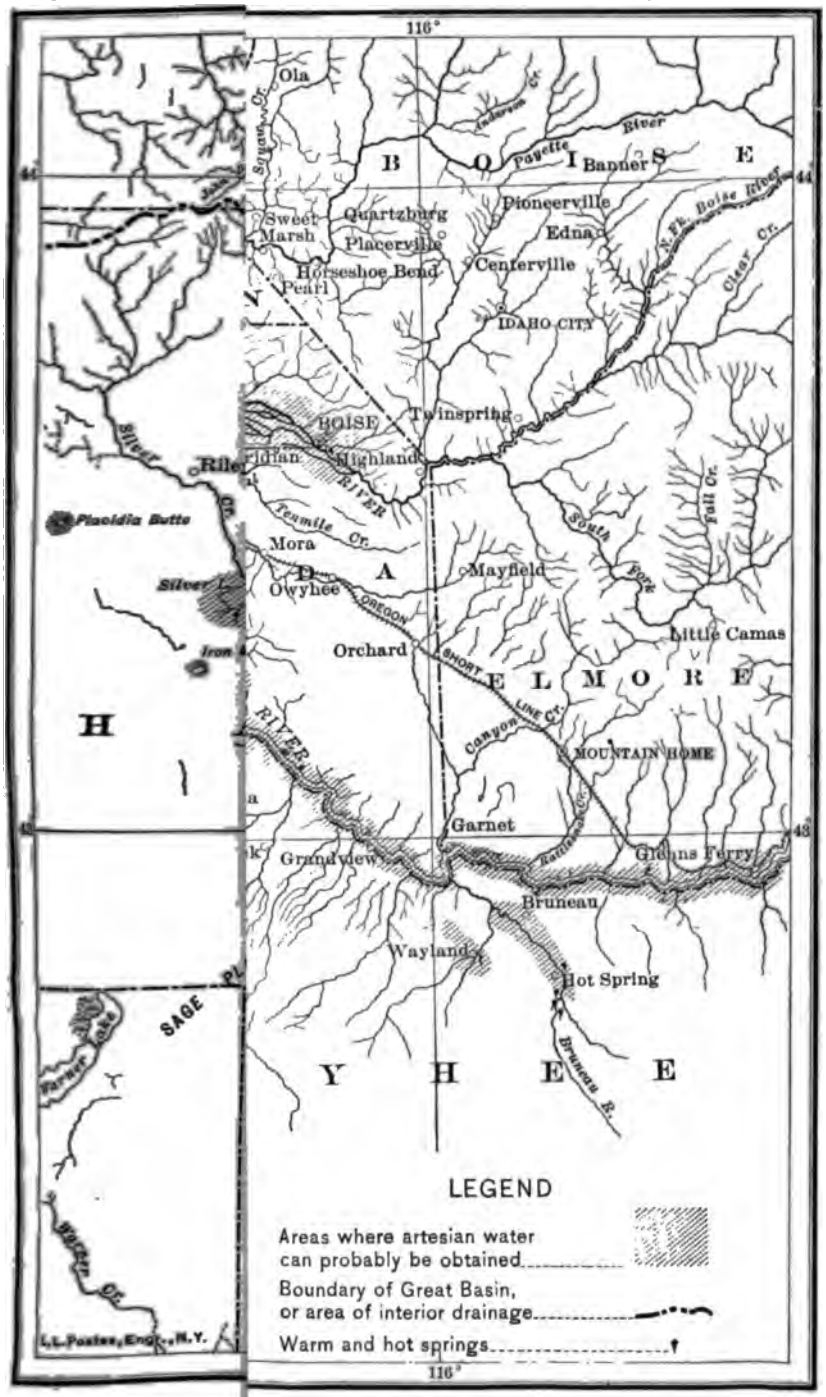
A classification of the most common rocks of southwestern Idaho and southeastern Oregon, sufficiently accurate for the present purpose, is as follows:

- Sedimentary rocks: Conglomerate, sandstone (in part hardened so as to form quartzite), shale, clay, sand, and gravel, together with beds of volanic dust and volcanic gravel or lapilli.
- Igneous rocks:
  - Volcanic rocks:
    - Lava flows: Basalt; Rhyolite.
    - Fragments blown out of volcanoes: Basaltic lapilli; Rhyolitic dust and tuff. (Also mentioned above as forming sedimentary beds.)
  - Plutonic rocks: The molten material like that extruded from volcanoes at the earth's surface, but which cooled below the surface in fissures, etc.

SEDIMENTARY ROCKS.

The stratified rocks of the region examined, or those composed of fragments of older rocks which have been spread out in layers or strata by the waters of lakes and streams, comprise conglomerate or pudding stone; sandstones; soft, highly calcareous, usually nearly white shales; loose gravel, sand, white volcanic dust; and dark, usually yellowish, volcanic gravel or lapilli. These beds were, for the most part, deposited in lakes during Tertiary time.

Examples of the conglomerate and sandstones referred to may be seen in the hills near where the Owyhee joins Snake River, in the isolated hills near Vale, and in the conspicuous bluffs to the southeast of Malheur and Harney lakes, as well as many other localities. These rocks are usually dark yellow, but occasionally, as near Narrows, are nearly white, and in some instances are sufficiently compact to be used for building stone. Associated with the layers of consolidated pebbles and sand just referred to, and having a wide extent in both Idaho and Oregon, are soft, unconsolidated light-colored shales and marls, and thick beds of nearly white sand and light-colored clay. Beds of this general nature, aggregating more than 1,000 feet in thickness, underlie Snake River Valley between Glenns Ferry and Weiser, and form the conspicuous white bluff along each side of that stream. Similar beds occur also in the lower portion of the valley of Malheur River and beneath the rim rocks of the canyons on the west slope of Stein Mountain. Light colored, and in part greenish shales, outcrop on the west side of Alvord Valley, where they pass beneath the sheets of basalt forming the bold eastern face of Stein Mountain. Fine exposures of rain-sculptured lacustral sediments, usually of a peculiar light-greenish tint, occur on the borders of Owyhee River near *the mouth of* Jordan Creek. Similar beds are present also in the


116°
Ola
Sweet Marsh
Quartzburg
Placerville
Horseshoe Bend
Pearl
Pioneerville
Edna
Centerville
IDAHO CITY
Banner
BOISE
Twinspring
Highland
Riley
Placidia Butte
Mora
Owyhee
Mayfield
Orchard
Little Camas
ELMORE
MOUNTAIN HOME
Garnet
Grandview
Glenns Ferry
Bruneau
Wayland
Hot Spring
YHEE
SAGE
Parker Lake
Wilson Cr.
L.L. Postes, Engr., N.Y.
LEGEND
Areas where artesian water can probably be obtained
Boundary of Great Basin, or area of interior drainage
Warm and hot springs
116°

mountains of Owyhee County, Idaho, and are an extension southward of the thick sediments exposed along Snake River. This same formation extends northward from Snake River and is exposed near Boise, and in the valley of Payette River. From its abundant outcrops along the last-named stream, it has been termed the Payette formation by Waldemar Lindgren.[a]

While the Payette formation has a wide extent in Oregon, and possibly reaches to John Day River, where other similar beds outcrop, it is not positive that all the exposures of similar material as far south as Harney and Silver lakes were deposited in the same lake basin. The lacustral sediments beneath the basalt of Stein Mountain have a thickness of fully 1,000 feet, and, as now seems probable, are older than the Payette formation.

Interbedded with the sandstone, shale, etc., of the formations just mentioned, and frequently forming a considerable and at times seemingly the major part of their thickness, are beds of exceedingly fine, white volcanic dust. This dust was blown out of volcanoes during violent eruptions, and falling in lakes, or being washed into them by streams, became interbedded with other sediments or intimately commingled with them. Pure white, stratified volcanic dust, from 10 to 20 feet or more thick, may be seen in the hills on the lower course of Owyhee River, a few miles south of Owyhee. It is also splendidly exposed near Beulah. Outcrops of material of the same nature, conspicuous on account of their whiteness, occur beneath the rim rock near Diamond, in the borders of the small valleys in the northern portion of Owyhee County, Idaho, as well as at a large number of localities in the bluffs bordering Snake River.

An interesting fact in connection with the stratified beds briefly described above is that they contain the bones of animals which are now extinct, but which lived in large numbers in and about the ancient lakes in which the sand, clay, volcanic dust, and other material now exposed and eroded into hills and valleys was deposited. Throughout these same beds, but most abundantly in the thinly laminated white silts and beds of fine volcanic dust, occur fossil leaves, and less commonly the fruits of plants. These plant remains differ from the vegetation living on the earth to-day, and reveal the nature of the luxuriant forests that flourished in the now arid portions of the far West during the Tertiary period of geological history. The fossil bones and impressions of leaves and fruits referred to, and also the shells of fresh-water mollusks frequently associated with them, are of great scientific interest, as they furnish evidence in regard to past climatic changes and the gradual evolution of life on the earth, and enable geologists to determine the age of the beds in which they occur.

[a] Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 632–634; Twentieth Ann. Rept., Pt. III, pp. 98–99; Geologic Folio No. 45.

The sedimentary beds to which attention has just been directed are in many instances open-textured and of such a nature that water will readily percolate through them, while in other instances they are of the consistency of clay and tend to retain water in the porous beds, if any is present, between them. These conditions indicate that wherever the sedimentary beds have been bent or displaced from their original horizontal position so as to form basins, there is a probability that flowing water may be obtained by drilling wells.

It is reasonable to assume that quartzite or granite is present beneath the Payette formation and associated volcanic rocks, throughout the Snake River Valley. The quartzite is usually a yellowish-white and excessively hard rock, and was orginally a sandstone, but has been altered or metamorphosed, so that the separate grains of quartz sand are no longer distinguishable. The granite is composed principally of conspicuous crystals of quartz, feldspar, and mica, as may be seen in the extensive outcrops in the mountains to the north of Boise, and is of deep-seated igneous origin. When either of these formations is encountered in drilling, the hope of obtaining flowing water by continuing to a greater depth had best be abandoned.

IGNEOUS ROCKS.

VOLCANIC ROCKS.

The rocks which came from volcanoes are by far the most conspicuous of any of the formations in southwest Idaho and the adjacent part of Oregon, and are no doubt of greater extent and thickness than the associated sedimentary beds. They may, with sufficient accuracy, be classified as basalt and rhyolite, but a critical study will no doubt show that what is here termed rhyolite in reality includes several rock species.

Both the basalt and the rhyolite present two conspicuously different phases, due to the manner in which the material composing them was spread out on the earth's surface. These rocks while molten were in part extruded by volcanoes so as to form sheets, which in many instances flowed far and wide over the surface of the land before cooling. In other instances the lava, while yet in the craters from which it came, cooled sufficiently to become rigid and was shattered by steam explosions, and the fragments thus produced were blown into the air and widely distributed through the action of the wind, etc., as sheets of volcanic dust, volcanic gravel, or lapilli and angular fragments frequently of considerable size. The basalt was spread over the surface of the land, mostly in a molten and even highly fluid condition and the beds of fragmental material produced were relatively small. The rhyolite, to a great extent, was shattered at the time it was erupted, and the resulting beds of fragments were probably of greater extent and thickness than the sheets of the same material which were

spread out as lava flows. This difference in the behavior of the volcanoes from which the comparatively fusible basalt was erupted and of the volcanoes from which the more refractory rhyolite was discharged is of much significance in reference to the nature of volcanoes, but can not be discussed at this time.

The basalt is a black, compact rock, but is frequently cellular and even scoriaceous on account of the presence in it of steam cavities, and in many localities is columnar. In the region under review it occurs in widely extended sheets, which in general vary in thickness from about 20 to 80 feet. Fine examples occur all along Snake River, but more especially on the northern side of its canyon, in the canyon of Bruneau River, and in the hills and mountains of Malheur and Harney counties, Oreg. The finest exposure of basalt in the region visited by me in 1902, if not the most remarkable in the world, is to be seen in Stein Mountain. The eastern slope of that splendid mountain is composed of the broken and eroded edges of sheets of basalt, which dip westward at an angle of 3° to 4° at the crest of the uplift, but flatten rapidly when traced westward, and present an aggregate thickness of not less than 5,000 feet. Between the sheets of basalt, as observed in at least eighteen instances, there are beds of coarse sandstone, varying in thickness from a few inches to 6 feet. Where the beds of sandstone occur the sheets of basalt are in general about 60 feet thick. From this and other similar evidence the total number of lava flows which occur at the locality referred to is estimated at between 80 and 100.

The widely extended sheets of basalt just referred to, like the sedimentary beds with which they are intimately associated—the sheets of basalt and the beds of sandstone, shale, clay, etc., in many instances alternating one with the other—are of ancient date, and belong principally to the Tertiary division of geological history.

Volcanic eruptions have occurred, however, at intervals from the time the oldest sheets of basalt were poured out in a molten condition down to almost the present day. Recent volcanoes, which discharged great quantities of basaltic lava in the condition both of lava sheets and of angular fragments, occur at three localities in southeastern Oregon. One of these is situated a few miles west of Diamond, Harney County, where there are craters that are built in part of scoria, lapilli, etc., and in part of lava sheets, and are surrounded by extensive lava flows. This group of small volcanoes may with propriety be named the Diamond craters. About 6 miles northeast of the former Bowdens post-office, in Malheur County, and approximately 18 miles south of Owyhee River where Jordan Creek joins it, there is an isolated crater of recent date, built almost entirely of congealed lava, which cooled about the opening in the earth from which it rose. About this Bowden crater, as it may be termed, is a recent lava flow which came from it and spread over at least 150 square miles of coun-

try. The most instructive as well as the latest of the three recent eruptions referred to occurs in the east-central part of Malheur County from 15 to 20 miles west of Jordan Valley, and the hills it built are here named the Jordan craters. The Cow Creek lakes owe their existence to the obstruction to the drainage caused by the extensive sheet of fresh black lava which came from the most northerly and most recent of Jordan craters. The rocks extruded from these recent volcanoes were spread over the surface both as lava flows and as sheets and piles of fragments, and serve in a most instructive manner to illustrate the mode of origin of the more ancient and far more extensive accumulation of similar rock.

The rhyolite, like the basalt, occurs both as massive sheets, which were poured out from volcanoes in a molten condition, and fragmental deposits, which also form well-defined beds. Of the beds originating in these two ways, the sheets of angular fragments, now in many instances firmly cemented and forming a rhyolitic tuff, are far more numerous and more extensive than the associated rhyolitic lava beds. The deposits of white volcanic dust described above as forming a part of the sedimentary formations are composed of the finest of the fragments blown into the air by the volcanoes from which came the material now forming the sheets of rhyolite and of rhyolitic tuff.

The compact, massive rhyolite is lighter colored than basalt, and in Idaho and Oregon is usually purplish on fresh surfaces, but weathers to a rich brown or red. It contains conspicuous crystals and grains of quartz, feldspar, and other minerals, and hence usually appears spotted. Frequently the crystals and grains referred to exhibit an arrangement such as would be produced by a flowing motion in the glassy base in which they are embedded.

The rhyolitic tuff is composed of angular fragments of the rock just described, which in most instances are firmly cemented so as to form sheets that are nearly, if not fully, as resistant to atmospheric conditions as the similar material which cooled from fusion without being shattered, as may frequently be seen in the rim rock on the sides of canyons and valleys.

Extensive exposures of rhyolite and of rhyolitic tuff occur in the mountains on the northeast side of Harney Valley, sometimes termed the Crow Creek Mountains. The conspicuous rim rocks on each side of Rattlesnake Creek, near Harney, are of rhyolitic tuff, while certain of the beds, usually cavernous on the weathered outcrops lower down in the walls of the same canyon, are of rhyolite which has a peculiar concentric or spherulitic structure. Again, in the bluffs of Silvies River, to the west of Burns, the edges of a thick sheet of compact tuff are well exposed, and similar rock has a wide distribution in the forest-covered mountains in which Silvies River rises. Other exposures of tuff and of compact rhyolite occur about Silver Lake, at Iron Mountain, and in the Mahogany Mountains. The conspicuous rim

rocks in the vicinity of Diamond are composed of tuff, and similar rock has a wide distribution in the hills near Smith and Mule.

An interesting fact in connection with the sheets of rhyolite and of rhyolitic tuff in southeastern Oregon is that they are younger than most of the basalt of the same region and overlie it. There have been eruptions of basalt, also, since the youngest observed sheet of rhyolite and of rhyolitic tuff was spread out.

The rhyolitic tuff is in many instances highly porous and permits the free percolation of water through it, but in other instances it is firmly cemented and probably nearly impervious. The compact rhyolite is to be classed, in most instances, as an impervious rock, although its weathered outcrops are at times conspicuously cellular. The presence of sheets of these rocks in an artesian basin, together with sheets of basalt and stratified sandstone, shales, clay, sand, etc., would tend to increase the variety among the strata, and in a general way, at least, be favorable to the storage of water under pressure.

PLUTONIC OR DEEP-SEATED IGNEOUS ROCKS.

The molten magmas which rise in volcanoes and in part overflow, so as to form lava sheets, also, in part, cool below the surface in the conduits of volcanoes and in fissures. Many distinctive features in the rocks produced from the same molten magma arise in this way, which it is unnecessary to consider at this time.

Both the basalt and the rhyolite, which occur in extensive sheets in Idaho and Oregon, came to the surface through openings, as fissures, for example, and below the present surface it is to be expected that there were many fissures in which molten rock has cooled, so as to form what are termed dikes. A few dikes were observed in the bold eastern face of Stein Mountain, and indicate that others may be present elsewhere. The dikes referred to are nearly vertical, vary in width 20 to 60 feet, and are horizontally columnar. As is well known, dikes have frequently led to the hardening of the walls of the fissures they occupy and for this and other reasons their presence in an artesian basin might introduce serious difficulties in the way of obtaining flowing wells. If in drilling a well, the locality chosen should chance to be directly above a dike, it is probable that the well would be a failure, even if the usually compact and hard rock of the dike could be penetrated. Where the country rock is concealed beneath deep sheets of soil, alluvial deposits, etc., it is frequently impossible to detect the presence of dikes in the rocks beneath the surface covering, unless they are encountered in drilling or making other excavations. So far as can now be judged, however, the dikes in the artesian basins described in this report are not numerous, and the chances of striking them in drilling are small. A greater danger lies in the fact that they may cut a pervious bed so as to prevent the percolation of water through it.

GEOLOGICAL STRUCTURE.

By geological structure is understood in part the positions occupied by stratified or bedded rocks in the earth's crust. For example, sandstone, shale, etc., originally laid down in horizontal sheets, are now found in many instances to be inclined or folded, and often occupy a vertical position.

The rocks, both sedimentary and volcanic, which underlie southwestern Idaho and southeastern Oregon, were at the time of their formation spread out in nearly horizontal layers, but subsequently they have been depressed in one locality and raised in another, and in certain instances crushed together so as to form great upward and downward folds. In other localities they have been broken along nearly vertical planes, and a portion of the strata on one side of the break has been upraised or depressed in reference to corresponding strata on the opposite side; that is, the beds have been faulted. Examples of gentle tilting of previously horizontal sheets of rocks throughout great areas are furnished in the broad Snake River Plains between Glenns Ferry and Owyhee. To the north of Snake River the rocks are now gently inclined upward to the north, but south of the river the same beds rise when followed southward, and in the Owyhee Mountains the strata are more than a thousand feet above the position they occupy beneath Snake River. This uptilting of stratified beds is well displayed in the hills near the point where Snake River first crosses the Idaho-Oregon boundary. These remnants of formerly much more extensive strata indicate not only the way in which once horizontal beds have been tilted, but bear evidence as to the great amount of denudation that has occurred throughout an extensive region.

Broad and comparatively gentle elevations and depressions of once horizontally stratified rocks occur also in other portions of the region examined; as, for example, in the neighborhood of Harney and Burns. The rocks beneath the extensive valley in which Malheur and Harney lakes are situated slope upward in the hills and mountains about the borders of the basin, as is well shown in the walls of the canyons on the west side of Stein Mountain, in the Crow Creek Mountains, on the border of the canyon of Rattlesnake River, in the hills west of Burns, and several other localities. In general, all about the Harney basin, as it is convenient to term the great depression in which Malheur and Harney lakes are situated, as well as in the country draining to them, the rocks are upraised. This basin, however, is not a simple saucer-shaped depression, but has irregularities, and is due to the association of several areas in which upheavals or depressions have occurred.

The broad, gentle undulations in the rocks just referred to, which in some instances have horizonital axes measuring a hundred or more miles, are promising structural features in reference to the hope of *obtaining an artesian*-water supply.

Of smaller size than the broad and usually somewhat indefinite swells and depressions referred to above are upward folds, or anticlines, and downward folds, or synclines. These are similar in shape and in the manner in which they are produced to the folds or corrugations that may be made by pushing one side of a pile of rugs toward its center; or, on a still smaller scale, by forcing together the sides of a pile of newspapers so as to compress them into folds. In the region under consideration there are several examples of such folds; but, as is commonly the case on all land areas, the relief produced in the manner referred to has been greatly modified by erosion. The upward folds particularly have been cut away, leaving for the most part only their basement portions.

A striking illustration of a great upward bend, involving bedded lava sheets having an aggregate thickness of fully 5,000 feet and a great but unknown thickness of stratified sedimentary deposits as well, is furnished by the north portion of Stein Mountain and the several parallel nearly north-south ridges to the east of it and north of Alvord Desert. The larger features of this rugged belt of country are due to the erosion of a great anticlinal fold, the longer axis of which trends about northeast and southwest. The hard layer of compact basalt in the truncated remnant of the fold now forms the sharp crested ridges to the east of Juniper and Mann lakes, which have a gentle surface slope on one side and a steep escarpment on the other.

A characteristic example of a broad downward fold or syncline may be seen from the summit of Stein Mountain on looking toward the southwest over the region drained by Donner and Blitzen River. The longer axis of this basin trends in a north-south direction and is inclined downward, or pitches, to the north.

Accompanying the bending of rocks so as to form corrugations, breaks sometimes occur, and the edges of the broken layers on the sides of the fracture are upheaved or depressed with reference to each other. In this and yet other ways what are termed "faults" are produced.

When the rocks have been broken and displaced or faulted, the conditions are not favorable for obtaining artesian water. Even if an artesian basin is present, the impervious beds, which would otherwise confine water under pressure, may be broken and permit the water to escape. In this connection it is to be noticed that hot springs are frequently situated on fault lines. In the case of the Stein Mountain fault, a spring with several surface openings having temperatures ranging from 168° to 177° F. occurs on the southwest side of Alvord Desert.

It is principally from the study of the structure of the rocks in any region that the presence of artesian basins is to be determined. The reason why structure may be considered as the controlling condition in this connection is because the other necessary conditions, such as the presence of pervious and impervious layers in a series of stratified

rocks, the presence of water in pervious beds, etc., are of common occurrence; while the requisite conditions for storing water beneath the earth's surface and under pressure are much less frequent, and it is these conditions which are dependent principally on the positions which the rocks occupy—that is, the geological structure. When a saucer-shaped basin is present, the chances are that the other necessary conditions will also exist.

ARTESIAN BASINS.

The four principal areas in southwest Idaho and southeast Oregon in which artesian water has already been discovered, or in which convincing evidence is found that it may be obtained, have already been referred to under the names of the Lewis, Otis, Harney, and Whitehorse artesian basins. Such facts as have been learned concerning each of these basins as are thought to be of immediate value to persons interested in the development of their artesian conditions are here presented.

LEWIS ARTESIAN BASIN.

The portion of this artesian basin in which flowing water may be obtained is situated along Snake River between Glenns Ferry and Weiser, and might with propriety have been named after it, except for the possibility that other artesian basins may be discovered in the extensive region it drains. Lewis, the less frequently used but more appropriate name of the Snake River, has therefore been selected as a convenient term by which to designate the artesian basin under consideration.

The rocks on each side of Snake or Lewis River from near the mouth of Kinghill Creek westward to beyond the Idaho-Oregon boundary are gently inclined or dip toward the canyon of the stream from each side. The inclination of the rocks is most readily seen on the south side of Snake River; as, for example, in the high lands to the east of Bruneau River, and in the hills near the mouth of Owyhee River, where the strata rise when traced southward at the rate of perhaps 100 feet to the mile. This rise, although gentle, is sufficient to carry the strata which underlie Snake River to an elevation of more than a thousand feet above its surface in the hills and mountains of Owyhee County. On the north side of Snake River the rocks are seemingly level, but, as nearly as can be judged, rise gradually to meet the mountains of older rock to the north of Mountain Home, Boise, etc. The inclinations of the rocks just referred to show that they have been bent into a broad trough-shaped depression, the longer axis of which bears about northwest and southeast, and is followed by the canyon of Snake River in a general way from Glenns Ferry to the Idaho-Oregon boundary. In certain localities, however, the axis of the fold is a mile or two north of the river.

On reaching Snake River, in 1901, I observed the general features pertaining to the dip of the rocks just referred to, and at once recognized the possibility of the presence of an artesian basin. Other conditions confirming the truth of this inference, such as the presence of warm and hot springs, were soon discovered, and the fact was learned that several successful artesian wells had already been drilled in Bruneau and Little valleys, thus demonstrating that water under pressure exists below the surface. In 1902 the portion of Snake River Valley lying west of the region traversed the previous year was examined, and the structural basin referred to was found to extend beyond the Idaho-Oregon boundary and to include a wide extent of territory in Oregon.

The eastern end of the Lewis artesian basin is for convenience considered to be near the eastern boundaries of Elmore and Owyhee counties, principally for the reasons that this is the eastern limit in the canyon of Snake River where land suitable for irrigation occurs below the artesian head of the basin as at present known, and also because sufficient study has not as yet been given to the region east of the counties mentioned to justify me in expressing an opinion in reference to the actual eastern extension of the basin in question.

The margin of the Lewis artesian basin can not yet be actually mapped, but within it is included, in a general way, the Snake River Plains in Elmore, Ada, and Canyon counties, and the country in Owyhee County which is drained by northward-flowing streams. In Oregon its boundary is still less definitely known, but it includes the greater part of the northern third of Malheur County. The position of the actual boundary of the basin, or the line from which the rocks begin to slope toward a central axis, is of much less practical moment, however, than the boundary of the country below the artesian head.

As will be stated below, the artesian head of the Lewis artesian basin has not been accurately determined, but provisionally it is taken at 2,500 feet above sea level. This is certainly a safe assumption, as flowing wells now discharge this water at that level, and others, as determined by a less accurate method of measurement, namely, the aneroid barometer, overflow at 2,700 feet above the sea. This indefiniteness is due to the fact that none of the wells in the basin are properly cased, and it was impracticable with the means at my disposal to make definite measurement of the water pressure. However, the area throughout the greater part of the Snake River Canyon or Valley, which is between an elevation of 2,500 and 2,700 feet, is comparatively small, and the extent of territory below the former level is probably more than sufficient to utilize all the artesian water that can be had within its boundary.

The tracing of the territory below the known artesian head in the portion of the Lewis artesian basin which is situated in Idaho is a simple matter, as most of it has been surveyed and accurate contour

maps are available. The maps referred to are published by the United States Geological Survey, and comprise the following sheets of the topographic atlas of the United States: Mountain Home, Bisuka, Boise, Silver City, Nampa, and Weiser.[a] By consulting these maps it will be seen that a large extent of territory adjacent to Snake and Boise rivers lies below the 2,500-foot contour. Practically all of the flat land favorable for agriculture adjacent to Snake River, between Glenns Ferry and the mouth of Boise River, lies below the horizon referred to. That is, the 2,500-foot contour marks, in general, the beginning of the abrupt slopes which rise from the flat lands bordering the river to the margin of the plateau above. In the region referred to, where the surface is less than 2,500 feet above the sea, wells put down to the requisite depth, which will be discussed later, should yield flowing water. A considerable extent of country about Nampa and Caldwell, much of the valley of Boise River, and of the Snake River Valley between the mouths of the Boise and Weiser, are also below the 2,500-foot contour, and so far as can now be judged, wells put down in this region should also yield an artesian flow.

There are no good maps of the region in Oregon embraced within the Lewis artesian basin, and it is impracticable to state at present where the plane of the assumed artesian head, 2,500 feet above the sea, intersects the surface. Much of the nearly level land that is otherwise favorable for agriculture adjacent to the west side of Snake River from where it first crosses the Idaho-Oregon boundary northward to the vicinity of Weiser, and an extensive tract in the lower 25 miles of the valley of Malheur River are certainly within the limit referred to, and careful tests of the artesian conditions should be made. A rough estimate of the extent of agricultural land in Idaho and Oregon that is within the Lewis artesian basin and below its known artesian head shows it to be not less than 1,000 square miles.

As the conclusions just presented will no doubt be considered too sanguine by many persons, I desire to indicate briefly the evidence, other than the geological structure, on which they are based, and at the same time to furnish data which will assist in the more complete development of the artesian conditions.

SPRINGS.

Within the Lewis artesian basin there are a number of warm and hot springs, which show that water under pressure exists below the surface.

Mountain Home.—About 3 miles east of Rattlesnake Creek, at the locality where "Old" Mountain Home was located, there is a fine spring, or group of springs, with a maximum temperature of 167° F.

[a] These maps, on a scale of about 2 miles to 1 inch, with a contour interval of 100 feet, each sheet including about 850 square miles, can be purchased of the United States Geological Survey for 5 cents each.

The surface level is about 3,550 feet. The water is of good quality, but is not now utilized except in a small way for bathing. No attempt has been made to develop the spring by boring, although good land occurs near at hand on which any water that might be obtained could be used for irrigating.

Boise.—Springs issue from sandstone of the Payette formation, 4½ miles east of Boise, at an elevation of about 2,750 feet. The water has a faint smell of sulphureted hydrogen, contains a small amount of mineral matter in solution, and varies in temperature from 125° F. to near the boiling point.

Salmon River.—A small spring on the left bank of Snake River, about 4 miles above the mouth of Salmon River, Cassia County, has a temperature of 131° F. Another hot spring occurs in the canyon of Salmon River, about 5 miles above its mouth.

Little Valley.—Near the head of Little Valley, Owyhee County, there are several warm springs and one small hot spring, temperature 101° F., which is now partially developed by drilling wells near it to a depth of 40 feet.

Bruneau Valley.—Near Hot Spring post-office there are several copious springs, with a temperature of 109° F. One of these has been developed by drilling a well near it to a depth of 240 feet. The well furnishes 7 gallons of water per minute.[a]

Walters Butte.—A copious spring about 1 mile west of Walters Butte, Canyon County, where the elevation is 2,340 feet, has a temperature of 67° F. This spring is very likely due to the leakage from water-bearing strata, and suggests that wells put down in its vicinity to a depth of about 350 or 400 feet would yield a surface flow of water. Near Walters Butte there is an area of about 4 square miles of favorable land that lies below the known artesian head of the basin in which it is situated.

Enterprise.—On the south side of Snake River, at Enterprise, Owyhee County, there is a spring issuing at an elevation of 2,220 feet, with a temperature of 128° F., which discharges approximately 7 cubic feet of water per second and is now utilized for bathing and for irrigating about 10 acres of land. The water rises where there is a thickness of nearly 1,000 feet of soft lake sediment (Payette formation) and, as its temperature indicates, comes from a depth of approximately 4,500 feet.

Sands.—From 2 to 3 miles west of Sands, in Owyhee County, and near the point where Poison Creek descends through a deep cleft in the upland and enters Snake River Valley, there are copious springs, with a temperature of about 100° F., which are used for irrigation. These springs rise where the surface level is approximately 2,450 feet, and may reasonably be supposed to be supplied by the leakage of porous

[a] Concerning the five localities mentioned above additional information is presented in Bull. U. S. Geol. Survey No. 199.

beds in the Payette formation. They occur within the Lewis artesian basin, nearly up to the known artesian head of that basin, and are a favorable indication that wells drilled in their vicinity to a depth of approximately 1,000 feet would prove successful, but from other evidence it is to be presumed that flowing water might be expected on drilling to a less depth. To the north of the conspicuous line of bluffs trending northwest and southeast and passing Sands on the south is a large tract of good land, embracing in fact something like 100 square miles, which is below the level of the springs just referred to, and where one is justified in assuming that artesian water can be had.

Owyhee Canyon.—In the canyon of the Owyhee, about 6 miles south of Owyhee post-office, there is a copious hot spring, which issues from openings in volcanic rock and has a temperature of about 115° F. But little irrigable land occurs near this spring, and for this reason an attempt to develop it and concentrate its flow would at present not be warranted.

Vale.—At Vale, on the east border of Malheur River, there is a spring with a temperature of 198½° F. Near at hand a well put down to a depth of 140 feet yields a strong flow of water with the same temperature. These springs are in a broad region underlain by the Payette formation, but it is presumed, are supplied by fissures. These springs rise at the west base of a prominent hill, composed in part of cemented gravel, and the manner in which they are depositing mineral matter suggests that the pebbles and sand in the hill were cemented by the same process. Other similar hills or buttes are situated a mile or two northward, and another is a conspicuous object about 5 miles farther north. Each of these exceptional features in the topography of the valley is due to the resistance offered to erosion by the hard beds they contain, and suggest that in each case hot springs rising through the Payette formation have led to a local hardening of its more porous strata and, in consequence, their preservation as erosion progressed. This suggestion was not tested by examining each of the hills referred to, but may be of interest to students of geology who visit them in the future, and in addition may be found to explain the manner in which hot springs sometimes occur in artesian basins, but do not appear to have any connection with neighboring artesian wells.

Westfall.—On the stage road between Vale and Westfall, in sec. 9, T. 18 S., R. 43 E., there is a spring with a temperature of 168° F. at an elevation by aneroid barometer of 2,400 feet. This discharges by estimate about 2 miners' (California) inches, or 100 cubic inches per second, but the total flow from the several small openings is probably greater than this. The waters have a slight odor of sulphureted hydrogen, and are depositing lime in the form of cellular calcareous tufa. The water is used for bathing, and in part is conducted to a house

rough a pipe and used for cooking, etc. A small spring near at and, supplied by percolation from the alluvial material in the bed f Bully Creek, has a temperature of 54° F.

The hot spring just mentioned is within the territory included in he Lewis artesian basin, and, judging from the approximate measures vailable, is below the artesian head of that basin, but owing to the igh temperature of its waters and the consequent depth from which hey rise, and the nature of the rocks in the vicinity, little if any significance in reference to the probability of obtaining artesian water in its neighborhood can be attached to it.

Beulah.—Small springs in the valley of Warm Creek, near Beulah, have a temperature of 185° F.

DRILLED WELLS.

In the portion of the Lewis artesian basin examined by me in 1901 it was found that several moderately deep borings had already been put down, several of which yielded a surface flow of water. Some account of the borings referred to was presented in my report for the year named,[a] but for the purpose of bringing together all the available evidence furnished by borings concerning water pressure, etc., within the Lewis artesian basin a brief account of those previously described is here inserted.

Boise.—To the north and east of Boise and within 2 miles of the city several flowing wells have been obtained by drilling in the Payette formation, and the water they supply is now utilized for city purposes. Boise is fortunate in possessing both cold and hot artesian wells. The following facts concerning them are compiled from a report on the geology of the Boise region of Waldemar Lindgren.[b]

The several cold artesian wells at Boise (temperature about 55° F.) are situated in the gulches north of the city and at an elevation of about 2,750 feet. They vary in depth from 400 to 609 feet, but since this information was obtained some of them have been deepened. The materials passed through in Hulls Gulch are sand and sandstone, 200 feet, and clayey beds, 200 feet, below which water was obtained. In the deepest well there are below the clay 40 feet of sand, 20 feet of clay, and 46 feet of solid basalt, below which clay occurs again. These wells yield from 40 to 250 gallons per minute, and their combined flow is stated to be about 670 gallons per minute. The water is stored in a covered reservoir and from there conducted into the city water mains.

Two wells drilled on the Davis ranch, in the next gulch north of Hulls Gulch, to a depth of 150 feet yield 40 gallons of water per

[a] Bull. U. S. Geol. Survey No. 199.

[b] Geologic Atlas U. S., folio 45, Boise, Idaho; published by the U. S. Geol. Survey and sold for 25 cents per copy.

minute. A well drilled to a depth of 400 feet in a ravine south of Hulls Gulch passed through clay and failed to reach water under pressure.

The hot artesian wells at Boise are situated two miles southeast of the city. Three of these, the water of which is piped to the city and extensively used for heating, baths, etc., have depths of 394, 404, and 455 feet. The character of the rocks penetrated is not definitely recorded, but it is stated that the drill, after passing through sandstone, penetrated several sheets of basalt, below which occurred red volcanic tuff or fragmental volcanic rock more or less thoroughly cemented and containing much black sand. The combined discharge of the three wells is 550 gallons a minute. The water is slightly charged with mineral matter in solution (about 300 parts in 1,000,000) and has a temperature of 170° F. The surface elevation is nearly 2,800 feet, and the water is under sufficient pressure to cause it to rise in a tube open at the top about 50 feet above the surface, or to an elevation of 2,850 feet above the sea. Several wells have been drilled on the United States military reservation a mile east of Boise, at least two of which discharge warm water. Their depths are 450 and 482 feet. The surface elevation is 2,850 feet. From the first mentioned a small flow of water with a temperature of from 75° to 140° F., increasing with depth, was obtained. The second gave a flow of about 35 gallons per minute, the water having a temperature of 90° F. These wells are located near a small tepid spring, and penetrated first 130 to 160 feet of sandstone, then 72 to 116 feet of hard, black lava (basalt), below which occurs a series 200 to 250 feet thick of clays and red basaltic tuff rich in magnetite (black sand) and sometimes containing also iron pyrites.

Other artesian wells in the neighborhood of Boise are briefly described in the Boise folio referred to above.

Both the cold and the hot artesian wells near Boise are in the Payette formation and associated and interbedded sheets of basalt which underlie the Snake River Plains. These same beds outcrop on the border of Snake River Canyon, and south of Snake River rise to an elevation of 4,000 feet or more in the Owyhee Mountains. These facts, together with the geographical position of the wells and the elevation at which they are located—that is, about 2,850 feet—render it at least possible that they belong to the Lewis artesian basin.

Bruneau Valley.—In the upper portion of Bruneau Valley there are three flowing wells, each 2½ inches in diameter, which, together with the numerous hot springs of the same region briefly described above, show that an abundance of water exists at a moderate depth and under sufficient pressure to cause it to rise to the surface if openings are provided.

On W. N. Roberson's ranch, about 2 miles north of Hot Spring

post-office and on the west side of the valley, a drilled well having a depth of 240 feet delivers about 7 gallons of water per minute, having a temperature of 109° F. This well is within a few feet of a large hot spring having the same temperature, the flow of which was not diminished when the well was drilled. The elevation of the surface at this point, by aneroid, is 2,750 feet. The section passed through, as reported from memory by Mr. Roberson, is as follows:

Section at Roberson's ranch.

	Feet.	Inches.
Light-colored sandy clay (Payette formation)	236	
Granular black layer, like basalt (volcanic lapilli)		10
Blue clay (Payette formation)	4	
Black lava	Several inches.	
Total depth, approximately	240	

The water is used for household purposes and for irrigation.

Nearly opposite the well just described, on the east side of the valley and at an elevation approximately 50 feet higher, a well drilled to a depth of 230 feet, on land belonging to Mr. A. H. Pence, gave a small surface flow.

On B. Whitson's ranch, on the eastern side of the valley, about 3 miles north of the two wells just mentioned, where the surface elevation is by aneroid 2,750 feet, a well 700 feet deep discharges about one-third cubic foot of water per second. The temperature is reported to be 90° F.

These three wells derive their water from different depths, and seem to indicate that water under pressure exists in at least three disconnected pervious layers, or else that a source of supply more deeply seated than has been reached by any of the drill holes yet made charges porous beds above it through fissures. The abundance of hot springs in the same vicinity apparently favors the latter hypothesis.

Little Valley.—Near the head of Little Valley, 9 miles west of Bruneau, there are five flowing wells, which range in depth from 150 to 215 feet, each drilled with a 2½-inch bit and poorly cased. The water is of good quality and has a temperature of about 67° F. The flow varies somewhat with seasonal changes, being greatest in winter and spring and least in summer and fall. In most of these wells the pipes have become clogged and the discharge is small. One of the stronger of the wells delivers in August a gallon of water in seven minutes, and is said to discharge about a gallon per minute in winter. Neighboring springs have various temperatures, ranging from 56° to 59° F.

These shallow wells, some of which began to flow when a depth of 60 to 70 feet was reached, are in a broad, deeply filled alluvial valley and evidently depend for their water supply on an alternation of pervious and impervious beds in the alluvial deposits. The source of the water for the several cold springs is no doubt the creeks which

flow from the mountains to the south, but the wells must be supplied from a deeper source.

Little Valley is situated within the Lewis artesian basin and is lower than the flowing wells near Hot Spring post-office, in Bruneau Valley, but the wells referred to above do not furnish a test of what may be termed the true artesian condition. Near the wells just described, but nearer the head of Little Valley, there is a small hot spring which rises through soft, white lake beds, and which has a temperature of 101° F. Five drill holes, put down to a depth of 40 feet in the immediate vicinity of this spring, resulted in a marked increase in the outflow. The discharge is now about one-half cubic foot per second. The wells are not cased, and there is reason to believe that larger holes, with proper casing, would lead to a greater discharge.

Guffey.—In the small valley cut by Dry Creek, about 1½ miles southwest of Guffey, Owyhee County, a well drilled to a depth of 568 feet, but not completed when examined (July 12, 1902), passes through 30 feet of loose surface gravel and then about 538 feet of soft light-covered strata belonging to the Payette formation, containing three seams of hard material, and reached a hard rock, perhaps quartzite, which checked the drill. The well is 3 inches in diameter. A surface flow was obtained from a depth of 160 feet, and an additional flow at 416 feet. The discharge is nearly 1 cubic foot of water per minute; temperature 76½° F. The well is not cased below a depth of 38 feet. Elevation at surface 2,375 feet, or about 160 feet above the adjacent portion of Snake River.

In a small gulch at Guffey and about 120 feet above Snake River, a well bored with a 1½-inch hand auger to a depth of 30 feet through light-colored beds, probably shale of the Payette formation, at first discharged about 1 gallon of water per minute, but has since ceased to flow.

Central.—Near Central (Barnard Ferry), in the Snake River Canyon, and from 7 to 9 miles northwest of Guffey, four artesian wells have been drilled. All of them are situated near the bottom of the valley, and within a distance of 1½ miles of Central, toward the southeast, where the elevation is approximately 2,300 feet. The records of these wells are as follows:

On the land of Alfred Cox a 3-inch well completed in June, 1902, has a depth of about 1,033 feet. It is cased from surface to a depth of 39 feet and discharges by estimate one-half gallon of water per second; temperature 100° F. Flowing water was first reached at a depth of 600 feet, and the delivery at the surface steadily increased as long as drilling was continued. The water brings sand and gravel to the surface with it. The contract price of the well was 25 cents per foot, the owner furnishing wood and water for the engine used in drilling. The casing used was also provided by the owner of the land and cost about 50 cents per foot.

About one-half mile west of the Cox well a boring approximately 1,000 deep was put down in 1901, which failed to reach water under sufficient pressure to force it to the surface. No other record in reference to this boring has been obtained.

On the farm of P. B. Smith, adjacent to the land of Mr. Cox, and about 1¼ miles southeast of Central, an artesian well drilled in 1901 has a depth of 940 feet, is 3 inches in diameter, is cased to a depth of 30 feet, and discharges about one-third of a gallon of water per second; temperature 98° F. Water which rose to the surface was first reached at a depth of 550 feet. At 700 feet a seam of black sand, etc., was penetrated and the flow of water increased. At the bottom of the well the drill dropped about 3 feet, having reached a stratum of sand and gravel, from which the main supply of water is derived. The well discharges sand and gravel. Cost about 25 cents per foot.

On the land of Mr. Barnard, about one-half mile southeast of Central, a well drilled in 1901 has a depth of about 1,035 feet, is 3 inches in diameter, cased for a short distance at the top, and discharges, by estimate, 1 gallon of water per second, with a temperature of 106° F. At Mr. Barnard's home, in Central, a well drilled in 1901 to a depth of 720 feet, delivers about three-fourths of a gallon of water per second, not measured, with a temperature of 99 or 100° F.

The four wells near Central just referred to were all drilled in the unconsolidated lacustral deposits, mostly sandy clays and soft shales of the Payette formation. A notable fact in connection with them is that no sheets of basalt were encountered. The water from each of the wells is used for irrigation.

Enterprise.—About 3½ miles down Snake River from Central or Barnard Ferry is the post-office known as Enterprise, situated near Warm Spring Ferry. Within a radius of about 1¼ miles of Enterprise and to the southeast there are 4 artesian wells.

At the home of George Newell there are 2 flowing wells, one with a depth of 340 feet, cased with 2½-inch pipe, temperature of 87° F., and the other 385 feet deep, 6 inches in diameter; temperature 90° F. The surface elevation is about 2,300 feet. The flow of water from the larger well, particularly, is strong, but on account of leakage about the pipe could not be measured. An estimate places the combined flow from the two wells at about 1 gallon per second. The water is used for irrigation. About 1½ miles southwest of Mr. Newell's home, where the elevation is 2,500 feet, a well drilled in 1901 to a depth of 165 feet, diameter 10 inches, discharges, by estimate, about 2 gallons of water per second; temperature 87° F. The water is used for irrigation. This well was begun in igneous rock, probably rhyolite, but at a depth of a few feet entered clay, and below the clay several changes in the nature of the material occurred, but an accurate record has not been preserved. Near where the well was drilled

there is a small spring of warm water. Approximately one-half m west of Mr. Newell's ranch, on land reported to belong to Mr. Shirle a well was drilled in 1891 to a depth of about 580 feet.

The four wells just referred to, with the exception of the 10-in well, were drilled in the light-colored sedimentary beds of the Pa ette formation and, like those near Central, have surprisingly hi temperatures for their depth. They are within a distance of miles of the copious hot spring at Enterprise, which has a temper ture of 128° F., and, as it seems justifiable to assume, derive a part their water at least from that or some other similar source.

Ontario.—The records of two drill holes made at Ontario, Ore are as follows:

A well owned by the city of Ontario, incomplete in October, 19 has, as I am informed by Mr. A. L. Sproul, of Ontario, a depth 1,025 feet, is 4 inches in diameter, and reached water at 195 fe which rose to within 6 feet of the surface. The material pass through is sand and gravel to a depth of 35 feet and the remaind blue clay. The water is charged with gas, which, when prope confined, burns constantly. Cost of the well, $750.

The well just described is situated where the surface elevation between 2,100 and 2,200 feet, or well below the artesian head of t Lewis artesian basin. The well is not cased, and the rise of the wa to within 6 feet of the surface makes it probable that if proper te of the water pressure should be made it would be found that a s face flow could be had by putting in proper casing.

The second well at Ontario, owned by A. F. Boyer, completed Se tember, 1902, 3 inches in diameter, has a depth of 215 feet; wa rose and overflowed. Gas is discharged with the water. Mater passed through: Soil, 10 feet; gravel, 20 feet, and the balance sha Cost, $100.

Vale.—A flowing well at Vale, Oreg., drilled near a hot spring a depth of 140 feet, as already stated, discharges a strong flow water so long as the casing is not obstructed by mineral mat deposited from it, and has a temperature of 198½° F. This well m be considered as a developed hot spring and has but little significa in reference to the artesian water supply of the basin in which it located.

Summary.—The artesian wells near Guffey, Central, and Ent prise collectively present certain interesting facts. They are loca essentially on a line extending northwest and southeast and meas ing about 11½ miles. At the west end of the line is the hot spring Enterprise. The depth of the wells and their temperatures are follows, beginning at Guffey and approaching Enterprise:

Depth and temperature of wells at Guffey, Central, and Enterprise.

Locality.	Distance from Enterprise hot spring.	Depth.	Temperature.	Temperature gradient.
	Miles.	*Feet.*	*Degrees F.*	
Guffey	11¼	538	76½	18.42
Central	5	1,033	100	19.66
Do	4½	940	98	18.54
Do	3¾	1,035	106	17.57
Do	3½	720	100	13.40
Enterprise	1	340	87	7.83
Do	1	385	90	8.37
Do	1½	165	87	3.10
Enterprise hot spring			128	

The temperature gradient, it will be remembered, is obtained by dividing the depth of a well below the stratum of no seasonal variation in temperature, assumed as 50 feet, by the number of degrees the temperature of the water discharged exceeds the temperature of the stratum of no seasonal variation, assumed to be 50° F. The temperature gradient, then, shows the depth in feet for each increase of 1 degree in temperature.

As is indicated in the above table, the temperature gradient in the region considered increases in a conspicuous manner as the distance from the Enterprise hot spring decreases. An exceptional increase, however, is seen in the case of the last well mentioned in the table, which, as noted above, is near a small tepid spring, and no doubt for this reason shows a more rapid increase of temperature with depth than any of the others. Not considering the well just referred to, the temperature gradient increases as the Enterprise hot spring is approached, but the rate of increase can not be accurately determined from the data available, since the wells are not cased and are not supplied from the same stratum.

The facts just presented seem to indicate that the porous beds in the Payette formation in the vicinity of Enterprise are supplied in part at least from the hot spring at that place. A legitimate conclusion seems to be that the rocks beneath the Payette formation are fissured and that hot water rising through the fissure has charged the porous beds above. Whether there is a deep artesian basin beneath the Payette formation or not there are no data for judging. In general, however, hot springs rise through deep fissures and are probably in most cases not an indication of the presence of a true artesian basin. As has already been stated, the Lewis artesian basin was formed by a bending of the rocks after the Payette beds were laid

down, and this bending no doubt affected a great thickness of the earth's crust below the beds now forming the surface. For this reason it is possible that a true artesian basin exists, the porous beds of which are depressed in the vicinity of Snake River to a depth of 4,000 or 5,000 feet.

In addition to the supply of water reaching the Payette beds from below, the shape of the basin and the fact that the beds composing it outcrop in the hills and mountains bordering the Snake River Plains on the north and south make it evident that additional water may reach the central part of the basin by descending from the surface.

The most logical conclusion to be drawn from all the evidence presented in reference to the probability of obtaining water in the Lewis artesian basin seems to be that flowing water may be expected when a well is so drilled as to penetrate deeply or pass through the Payette formation at any locality within its borders where the surface elevation is less than 2,500 feet. As already stated, 2,500 feet is the minimum measure of the artesian head, as shown by existing wells, but the true artesian head may considerably exceed this amount.

The wells in Bruneau Valley, as shown by an unsatisfactory method, namely, aneroid barometer measurements, have an altitude of 2,700 feet; and the artesian head at Boise is about 2,850 feet. It is not safe at present, however, to accept any measurement of the artesian head in excess of 2,500 feet, and until more wells are drilled all attempts to obtain flowing water should be confined to localities below that horizon. It chances that nearly all the good land along Snake River and in the lower portions of Malheur Valley and much of that in Boise Valley are below 2,500 feet. Abundant localities for developing the Lewis artesian basin are thus available and should be tested before attempts are made to obtain artesian wells on the uplands.

The wells drilled in Snake River Valley at Central, Enterprise, Ontario, and other places passed through soft strata and did not show the presence of beds of basalt or other hard rock in the Payette formation. It is probable that only soft beds will be encountered in drilling to a depth of about 1,000 or 1,200 feet in the portion of Snake River Valley between Guffey and Weiser, but no positive assurance that such will be found to be the case can at present be given.

As may be judged from the facts above presented in reference to the occurrence of hot springs near the artesian well now flowing, the most favorable localities for drilling additional wells may be assumed to be near where warm or hot springs rise through the Payette formation. A qualification of this statement is suggested, however, by the fact that the hot spring at Vale is depositing mineral matter in the beds it passes through in rising toward the surface, and presumably in this way forms for itself a conduit which prevents its water from spreading laterally. This exceptional condition is also indicated by

the exceptionally high temperature of the spring referred to. In choosing a location for a well, therefore, it would be best, at least until more facts are gathered in this connection, to avoid the proximity of a hot spring that is depositing calcareous silica, tufa, gypsum, etc. The most favorable locality, so far as I can now judge, for continuing the development of the Lewis artesian basin is in the extensive flat in the Snake River Valley to the north of Sands.

EASTWARD EXTENSION.

On a preceding page it was stated that the Lewis artesian basin begins on the east near the mouth of Kinghill Creek, that limit being chosen mainly for the reason that but little land suitable for irrigation exists in the canyon of Snake River above the locality mentioned. The upraised rim of the basin extends farther east, however, but what its limits are is as yet unknown.

In my report on the geology and water resources of the Snake River Plains[a] some facts concerning artesian wells in and about the Rock Creek Hills were presented. It now seems not improbable that these wells are in reality situated in the Lewis artesian basin, and it may perhaps be shown by future investigations that the wonderful springs in Snake River Canyon, between Bliss on the west and the neighborhood of the mouth of Salmon River on the east, may be due to the escape of artesian water from the same basin. While there are no newly acquired facts to report concerning the region just referred to, lying south of Shoshone Falls, the study of the Lewis artesian basin certainly indicates that the probability of success in case wells are drilled there is greater than seemed evident when the report on the explorations was made by me in 1901.

OTIS ARTESIAN BASIN.

Otis Valley is situated on a creek of the same name in the extreme northeast portion of Harney County, Oreg., about 6 miles northeast of Drewsey. The valley has a flat bottom, measuring by estimate 5 by 6 miles in diameter, and contains a considerable amount of good land. About 1,900 acres are now under irrigation. The valley is underlain by sedimentary beds consisting largely of white volcanic dust, presumably belonging to the Payette formation. The bordering uplands are composed in part and perhaps principally of basalt, but the sedimentary beds and layers of volcanic dust which occur beneath the valley have also been bent upward in its elevated rim. The dip of the beds about the east side of the valley is west or toward its center at a low angle, and on the south side, as is revealed in the hills at Drewsey, the dip is northward. My examination was not so complete as I desired, but I think was sufficient to show that the valley is a structural basin, on the west side of which there is perhaps a break

[a] Bull. U. S. Geol. Survey No. 199, 1902.

or fault. The structure is such as to suggest the presence of an artesian basin, and in addition copious warm springs on its eastern side show that water under pressure exists below the surface. To term the region in which Otis Valley is located an artesian basin, however, will be justified only when the presence of water under sufficient pressure to force it to the surface is demonstrated, but the conditions observed seem to warrant a careful test by drilling. The pioneer well should be put down on the east side of the valley, a short distance to the west of the warm springs referred to. The area of the land below the level of the artesian head suggested by the elevation at which the warm springs come to the surface is about 10 or 15 square miles.

HARNEY ARTESIAN BASIN.

The region embraced within what is here termed the Harney artesian basin is so great that I could not in the time available examine it with the care it deserves, but I crossed it and visited various commanding summits so as to see more or less thoroughly its entire extent. The area embraced in the outer rim of the basin includes in a general way the region drained by streams which during the rainy season flow to Malheur and Harney lakes, and includes perhaps two-thirds of Harney County, Oreg. The principal streams referred to are Silvies River, which flows southward past Burns and enters Malheur Lake from the north, and Donner and Blitzen River, which rises on Stein Mountain, flows northward, and also enters Malheur Lake. The distance between the sources of these two streams is about 135 miles in a straight line. The breadth of the outer rim of the basin in an east-west diameter is somewhat indefinite, but measures approximately 50 miles.

The outer rim of the Harney artesian basin is sharply limited on the southeast from near Andrews northeast to beyond Juniper Lake, a distance of 50 or 60 miles, by the east base of Stein Mountain. Its eastern border is in the Crow Creek Hills, and from these it passes northward and curves about the head branches of Silvies River, and then, bending southward, passes to the west of Silver Lake, Iron Mountain, and south of Harney Lake to the source of Donner and Blitzen River. The border is well defined, except in the broad region, with comparatively mild relief to the southwest of Silver and Harney lakes, where the strata are in general nearly flat. The basin is not a single saucer-shaped depression, but consists of at least two troughs or synclines, one in the region drained by Silvies River and the other on the west side of Stein Mountain and drained by Donner and Blitzen River. There are, besides, other folds and irregularities which it is not necessary to describe at this time.

The statements just given indicate that the Harney artesian basin has a structure such as is favorable for the accumulation of water in any porous beds which may be present, but before it is decisively *pronounced an artesian* basin other evidence should be obtained.

SPRINGS.

There are several warm and hot springs in the broad, generally flat region about Malheur and Harney lakes, but only a few of these were visited by the writer.

Burns.—On the border of Harney Valley, beginning about 3 miles southwest of Burns, a number of springs come to the surface at the base of a cliff of basaltic agglomerate. These have a temperature of from 75° to 80° F. The surface elevation is about 4,100 feet by aneroid, or the same as the general level of the broad, flat lands flooring the valley to the south of Harney and Burns. These springs are of considerable volume, and, as I have been informed, flow throughout the year without sensible variations either in volume or temperature. The water is drunk by stock, but is not used for irrigation except so far as the raising of wild hay is concerned.

Little Sage Hen Valley.—A number of springs come to the surface in the flat, alluvial lands forming the bottom of Little Sage Hen Valley, and, spreading over the land, serve to irrigate extensive natural meadows. Their temperature is in general 63° to 64° F.

Silver Lake.—On the west side of Silver Lake, and along Silver Creek, between it and Harney Lake, there are several warm and hot springs, flowing only during the rainy season, the waters of which serve to naturally irrigate the adjacent lands. The valley of Silver Creek is a broad, flat, swampy meadow, on which great quantities of wild hay are cut every year.

Harney Lake.—To the southeast of Harney Lake and about one-half mile from its shore, there is a spring of clear, tasteless water, with a temperature of from 145° to 150° F. The volume is by estimate about 6 gallons per second. An attempt to utilize the water for irrigation has been abandoned. The spring is situated near the south base of a bold hill, composed mainly of sandstone, and rises through soft, usually white, lacustral sediments resembling the Payette formation.

Malheur Lake.—In the bed of Malheur Lake, near its southern end, and exposed in summer when the lake is low, there are small springs with a temperature of 64° F. Copious hot springs occur near the eastern end of the lake and at a distance of 4 or 5 miles from the bold bordering uplands of the valley, but these were not visited by me.

Summary.—All of the springs enumerated above present the usual characteristics of warm and hot springs, and furnish evidence that water under pressure exists below the surface. They are widely separated, and in all instances except, perhaps, at the locality near Burns, rise through the soft beds which floor the Harney basin. Their high temperature in several instances indicates that the water rises from a considerable depth, but not from a depth greater than that to which the beds in the basal portion of the basin are depressed. In this connection I *may state* that the lacustral sediments exposed

beneath 4,500 feet of basalt on the west side of Stein Mountain dip westward at an angle of 3° or 4°, their inclination gradually decreasing, however, with distance from the outcrop, and it is reasonable to assume that they pass under Harney Valley at a depth of certainly 6,000, and probably of 10,000 or more feet. Similar evidence of the great thickness of the strata which are deformed so as to make the Harney artesian basin is furnished in the portion of its upraised rim that forms the mountains to the west of Harney and Burns. Porous beds at any such depth as that just considered, however, are, for practical purposes, beyond the reach of the drill; but as the heated water, in several instances, rises to the surface through the strata forming the upper portion of the great series of rocks involved in the deformation of the basin, and through sedimentary deposits of later date now forming the floor of Harney Valley, there are reasons for believing that the porous beds near the surface have been charged in part with water from below and furnish artesian conditions.

DRILLED WELLS.

In addition to the testimony furnished by the geological structure and by springs, certain borings made near Harney and Burns favor the hope that flowing water can be had at a moderate depth in Harney Valley.

Harney.—About 5 miles east of Harney, on land belonging to Fred Haines, sec. 2, T. 23 S., R. 32½ E., a well 3 inches in diameter, drilled in 1896 to a depth of 507 feet, struck water at a depth of between 200 and 300 feet, which rose to the surface. The well is not cased, and the water now stands 6 feet below the surface and has a temperature of 49° F. The material passed through was soft to a depth of 100 feet, and below that depth consisted of black lava, clay, etc., but no definite record is available. This well at first yielded a true artesian flow, but, as nearly as can be judged, has caved in, owing to lack of casing, and the water supply at present is from percolation through porous beds near the surface. The temperature of the water now being pumped indicates that it comes from about 50 feet below the surface and has its ultimate source in the neighboring hills. The cost of drilling the well was $1 per foot.

Burns.—A well drilled at the expense of Harney County in 1893, at a locality about 6 miles southeast of Burns, in sec. 13, T. 23 S., R. 31 E., was continued to a depth of 848 feet. The well at the top has a diameter of 6 inches, but narrows near the bottom to 4 inches. At the depth of 350 feet water was reached which rose and overflowed at the surface, but after an attempt to improve the well, made in the spring of 1902, it ceased to flow. The water in August, 1902, stood 3 feet below the surface and had a temperature of 49° F. The first 100 feet of material passed through was sand, gravel, and soft rock, and at a greater depth hard rock was penetrated, but no record as to its

nature, etc., is available. Two water-bearing strata are said to have been reached, one at 350 feet from the top, and the other at the horizon, where drilling was discontinued, namely, 840 feet. The outflow from the first water-bearing layer is said to have been small. The well is cased with iron tubing, 6 inches in diameter, to a depth, as reported, of 450 feet. The cost to Harney County was $2,400, not including the casing. The drilling was done by George W. Kellogg, of Salt Lake City, Utah. Work is said to have been abandoned on account of the loss of drilling tools in the well.

A well drilled on land belonging to Thomas McCormick, about 5 miles southeast of Burns, in sec. 12, T. 31 S., R. 24 E., completed in 1900, 6 inches in diameter, has a total depth of 68 feet. The water now rises to within 16 feet of the surface and yielded 100 gallons per hour by pumping. The material passed through was soft, and water is reported to have been reached in blue clay. The cost of drilling the well was $85 and of the casing $21.

Summary.—The evidence furnished by the drill holes in Harney Valley is meager, but so far as it goes it favors the hope that artesian water can be had throughout an extensive territory.

The well near Harney and the county well near Burns furnished flowing water and, I feel justified in affirming, would have continued to flow and to furnish a valuable water supply in each case had they been properly cased and cared for.

The well on Mr. McCormick's land is too shallow to be of significance in judging of the artesian conditions at the locality where it is situated.

Nearly all the evidence I have been able to gather in reference to the geological structure, the warm and hot springs, and the results of drilling certainly favor the conclusion that beneath the extensive plain east of Harney and Burns, on which Malheur and Harney lakes are situated, there is an artesian basin.

Conditions which may exert an adverse influence upon the value of the basin, so far as flowing wells are concerned, are the low pass on the northeast of Malheur Lake, through which the water of that lake formerly escaped, and the somewhat indefinite character of the rim of the basin to the south of Silver Lake. In addition are the "accidents" that may be present in any artesian basin, such as changes in the texture of the beds, the occurrence of breaks across the strata, and the presence of dikes.

In reference to the low pass which extends in an easterly direction from the flat country east of Malheur Lake through the hills to Camp Creek, it is evidently the lowest place in the rim of the Harney artesian basin and may perhaps determine the artesian head within the basin, but there are reasons for delaying a conclusion in this connection. The channel referred to is strongly defined and has a broad, level floor, formed by a recent basaltic lava flow. The bottom of the

previously cut river channel is thus concealed and is at least 20 to 3
and perhaps more, feet below the present surface. The highest poi
in the pass or old river bed (as shown, I have been informed, by su
veys made with the view of drawing off the waters of Malheur Lak
for irrigation purposes in Malheur Valley) is but 20 feet above th
level of Malheur Lake. Evidently, then, the buried stream chann
beneath the lava is lower than the broad valley lands about Malhe
and Harney lakes and cuts across any porous bed that occupies th
entire extent of the basin. If water-charged porous beds were cut b
the channel, springs would be expected to occur in it. No spring
are present, however, and it is possible that the silting over of th
porous beds and the burial of the silt beneath lava has sealed them
so as to prevent the escape of water from them. While this is n
such an indefinite hypothesis as it may at first seem, it does not remov
all anxiety in reference to the influence of the old river chann
referred to on the artesian conditions in Harney Valley. The que
tion here raised can not be answered by the facts now known; neith
can a positive opinion be expressed in reference to the position of th
rocks to the southwest of Silver Lake, but my judgment is that neith
of these possibly adverse conditions is of sufficient weight to discou
age the drilling of test wells in Harney Valley.

From the elevations of the several localities at which warm and h
springs issue and of the surface of the two wells referred to abov
the artesian head may be assumed to be at such an elevation th
wells below the level of Harney or Burns would furnish a surfa
flow of water. The area of the basin below the horizon stated ca
not be accurately told at present, but embraces practically all th
level land in Harney Valley about Malheur and Harney lakes an
probably also the flat lands in the valley of Silver Creek and abo
Silver Lake. Extensive tracts of rich land in the region drained b
Donner and Blitzen River are also within the area in which artesia
water may reasonably be expected if drill holes properly cased a
put down. A rough estimate based on the general map of Orego
issued by the United States Land Office, indicates that the ar
within which artesian water may be expected is in the neighborho
of 1,000 square miles, but this includes Malheur and Harney lak
and the swamps bordering them.

To test the artesian conditions in the Harney basin, wells may b
put down at any locality below the level of Burns or Harney. Pe
haps the most favorable situations are near the warm and hot sprin
referred to, and at such places wells should be drilled on the side
the spring chosen, which is in the direction of the center of the bas
or, in general, toward Malheur or Harney Lake. The depth to whi
wells should be drilled must be determined by experiment, as suf
cient information is not in hand in reference to the sections expos
in the rim of the basin to warrant a judgment in this connectio

The successful well near Harney and Burns, however, suggests that favorable results may be expected anywhere in the basin below their surface elevation, at a depth of less than a thousand feet and possibly at a depth of only a few hundred feet. The possibilities of the basin, however, will not be exhausted when the drill has reached a depth of even 1,000 feet or, indeed, at a depth of 5 or 10 times that measure.

In the development of the basin an effort should be made to discover all of the water-bearing beds that are present within a reasonable distance below the surface, and in case several wells are drilled near each other, they should, so far as practicable, derive their water supply from different strata.

WHITEHORSE ARTESIAN BASIN.

Stein Mountain, as already stated, is the western slope of a great anticline. The central part of the upward fold referred to has been deeply eroded, and where faults occur, a subsidence has taken place. The position of the central and now deeply eroded portion of this great fold is occupied by Alvord Desert and the sharp-crested ridges running northeast from it. To the east of the Stein Mountain anticline or upward fold there is a flat-bottomed syncline or downward fold, in which Whitehorse Valley is situated. The rocks beneath this valley are bent into basin shape and the rim of the basin is high on all sides except the one adjacent to Alvord Valley. The rocks which have been bent so as to form a basin consist of reddish and brownish rhyolitic tuff in which angular fragments are conspicuous, black basalt, and light-colored and usually nearly white lacustral sediments and sheets of volcanic dust, resembling those characteristic of the Payette formation. The thickness of the beds exposed in the upraised rim of the basin—as, for example, in the mountains between Whitehorse Valley and Oregon Canyon, the next valley to the east—is several thousand feet. The bold bluffs on the west side of Oregon Canyon (which in the part here referred to is a broad valley with several ranches in its bottom) are formed of the edges of the sheets of rock, mostly basalt, which dip west and pass under Whitehorse Valley. Several springs issuing from the bluffs, well above their base, indicate that certain of the beds are water charged. These springs may reasonably be supposed to be the leakage from the basin to the west and suggest an abundant store of water beneath Whitehorse Valley.

In the southern part of Whitehorse Valley, about 6 miles south of the site of the former military post and at an elevation of fully 150 feet above the general level of the floor of the valley, there are springs with a temperature of about 100° F., which rise through soft white lake beds. In the northern part of the valley, about 10 miles north of the site of the former military post, as I have been informed, there is another warm or hot spring.

The facts stated above are such as to warrant a careful test of the artesian conditions in Whitehorse Valley. A boring should be made near the warm springs in the south end of the basin, a few rods north of the localities where their water now reaches the surface. A boring at Whitehorse ranch (the former military post) would probably yield flowing water, but the chances are nearly equally favorable all along the eastern side of the flat lands, which extend northward from the ranch for 10 or more miles. The area of good land within Whitehorse Valley, where it is reasonable to expect that flowing water can be obtained, is by a rough estimate not less than 30 square miles.

In the structure of the Whitehorse artesian basin there is one condition which may be detrimental to the occurrence of water in it under pressure, namely, the lowness of the rim of the basin on the west side in the vicinity of Sand Gap. The eroded borders of the beds emerging from beneath Whitehorse Valley there form a line of westward-facing bluffs, which define the east border of Alvord Desert. For the reason that there are no springs along the base of these bluffs, however, and for other reasons, the lowness of the rim of the basin need not be considered sufficiently important to deter the testing of the artesian conditions within it.

ARTESIAN WELLS IN ALLUVIAL DEPOSITS.

In regions like southern Idaho and eastern Oregon, which have an arid climate, and where bold mountains are bordered by wide valleys the streams from the uplands deposit much and in many instances all of the sand, gravel, etc., which they bring down from the high-grade upper portions of their courses on the border of the valley which they enter. In this way alluvial cones or fans are built about the mouth of gorges where they open out onto a plain. These alluvial cones are not infrequently several miles in radius at the base and several hundred or perhaps 2,000 or 3,000 feet high. The apex of each cone is at the mouth of or some distance within the gorge from which the débris of which it is composed was derived, and from which a stream usually flows, at least during a part of each year. These beds of débris are thus in a position to become water charged, and their structure is such that pervious beds may be confined between impervious beds. Large alluvial cones may thus furnish conditions for the storage of water under pressure, and especially on the outer portion may yield flowing water if drill holes are put down.

Alluvial cones are sometimes greatly extended and have low surface slope, and in fact merge by insensible gradations into the flood plains of streams. This is frequently the case in arid regions, where the valleys are in many instances deeply filled with alluvium. Valleys when thus partially filled have broad, flat bottoms, with a perceptible gradient or surface slope down their courses. In such instances the surface material is usually fine, but becomes coarse at a depth of a

few feet or a few score feet below the surface, and as the beds are gently inclined the coarse beds at a depth may be charged with water under pressure. If flowing water is obtained by drilling in alluvial cones or flood-plain deposits it is normally cold, for the reason that it has not descended into the earth far enough to be influenced by the interior temperature of the earth. The water is similar to that supplied by hillside springs, and in Idaho and Oregon would have a temperature of about 50° F.

There are a few localities in the region examined by me in Idaho and Oregon where the conditions warrant the drilling of shallow wells in alluvial cones on flood plains. Some of these located in Idaho are mentioned in Bulletin 199, already referred to. In Oregon tests of the nature referred to should be made in Willow Creek Valley, to the northwest of Vale, and in neighboring flat-bottomed valleys which have a perceptible downstream slope.

The alluvial cones on the east side of Stein Mountain, at the mouths of gulches down which streams flow, should also be tested with the drill. The most promising localities for such tests are from the outer margin of a cone to midway up its slope. When the cones are steep, however, the chance of water being stored in them under pressure decreases rapidly as their summit portions are approached. The test referred to should be carried down to at least the level of the flat lands in the adjacent valley unless favorable results are sooner reached.

SIZE OF DRILL HOLES, THE CASING OF WELLS, ETC.

In the development of the artesian conditions of the Lewis artesian basin, as experience has already shown, light, portable drilling rigs will probably be all that are required, since the beds to be penetrated are soft. In the other artesian basins named, however, it seems highly desirable that only the most efficient of drilling machinery should be employed, as hard rocks will have to be penetrated in probably all wells that are more than a very few hundred feet deep. An extensive experience in drilling wells in the oil fields of the United States has shown that the best outfit for use in the artesian basins of Oregon is the square derrick walking-beam rig, provided with the best tools that can be procured. It is perhaps needless to add that only well drillers of wide experience and known integrity should be employed.

The wells to be put down should, in my opinion, be 8 inches in diameter, or drills of this size should be use to as great a depth as possible before tapering the hole to any smaller size.

In all instances the wells drilled should be well cased with iron casing. Neglect in this particular has led to failures in many instances in both Idaho and Oregon where success, as there are reasons for believing, would have been attained if proper casing had been put in. For the sake of emphasizing the statement just made, it may be truthfully said that *water should* not be expected to rise in a hole drilled

through rocks of various descriptions, many of them, as is usually the case, being porous, any more than it should be expected to remain in a standpipe full of holes rising above the surface of the ground The water in an artesian well is under pressure—frequently great pressure—and tends to flow laterally wherever the rocks are porous or fissured. More than this, the walls of an uncased well are apt to cave and thus render useless all the work that has been expended on it.

In drilling a well the pressure of the water at each horizon where it is encountered should be carefully tested. One way of doing this is to lower a tube into the well, such, for example, as a three-fourths-inch iron pipe, with a leather bag filled with flaxseed encircling it near the lower end. The pipe should be lowered until its end is just above the place where water was struck. In such an experiment the flaxseed will swell and expand the bag containing it so as to shut off the escape of water about the outside of the pipe and allow it to rise within it. If the water overflows at the surface of the ground it demonstrates, of course, that an artesian flow has been secured, and if the pipe is continued upward the height to which the water rises within it will show the artesian head. Other suggestions in this connection may be found in a paper by Chamberlin, and in a report on Nez Perce County, No. 3 and No. 21, respectively, of the list at the end of this report.

Wells should be located as far apart as practicable, and when two or more water-bearing beds are present neighboring wells should have different depths, so as to draw their water supply from different sources. The distribution of wells in reference to the direction of flow of the underground water is also important. Obviously, if there is to be a series of wells, more or less in line, their alignment should be at right angles to the direction of underground flow, so as to decrease to a minimum the influence that one well exerts on its neighbor. Information in this connection is contained in the paper by Chamberlin, No. 3 of the list at the end of this report.

PRESERVATION OF WELL RECORDS.

If wells are drilled in the artesian basins described in this report a careful record of all facts concerning them should be preserved. This is a matter of great importance to all the people interested in the development of the artesian basins, and may lead to a great saving of money in other directions. As a practical method of obtaining and preserving information referred to, I wish to suggest that it be made the official duty of the county clerk in every county where drill holes are put down for any purpose to obtain and preserve a record of the facts relating to them. To assist in doing this a schedule is here inserted which can be printed, and which, after being filled in with the data required, should be filed at the county clerk's office for future reference. The schedule referred to is as follows (for greater convenience *each item* should be given a separate line):

WELL RECORD.

County, ——: State, ——.
County clerk, ——— ———. No. ——. Date, —— ——, 190–.

Owner of well, ——— ———. Driller of well, ——— ———. Post-office address, ——— ———. Location of well: Township —— —, range ——, sec. —. When completed, ——— ——. How put down: Dug, driven, bored, drilled, ——. Size or diameter, ———. Depth: Total, —— feet; to water, —— feet; depth of water, —— feet. Did water rise when struck? ——. Does water flow over surface? ——. Height to which the water will rise in an open tube, ——. Has the flow diminished or increased? ———. Quality of water: Hard, soft, salty, alkaline, ———. Temperature of the water, ——. How is water raised? ——. Cost of well, $——. Cost of mill and pump, $——. Is the well cased? ——. Cost of casing, ——. Amount pumped or flow per hour or day, ——. Water used for ——. Elevation of surface, —— feet.

Strata passed through and remarks: ——————.

LAWS.

As the water supply in an artesian basin may become of importance to a large number of citizens, it is obvious that laws governing its use are as necessary as the laws relating to surface waters, but, so far as I am aware, only one attempt to place legal restrictions on the utilization, or rather on the waste, of subsurface waters has been made in this country,[1] and that act fails in two particulars to meet the requirements outlined above—the proper casing of wells is not made obligatory, and the filling of abandoned wells is not provided for. Each of these regulations is highly important.

The principal restrictions and conditions which it is desirable should be established and enforced by law are as follows:

1. *Every drill hole in an artesian basin should be properly cased.*—By this is meant that an iron casing or tube lining the hole and made sufficiently tight to prevent water from rising outside of it should be put in every well which remains open. The lower end of the casing should be just above the water-bearing stratum.

---

[1] The following law providing for the conservation of artesian water has been passed by the legislature of the State of Washington:

CHAPTER CXXI.

(H. B. No. 266.

RELATING TO ARTESIAN WELLS.

AN ACT in relation to artesian wells and regulating the flow of water therefrom, and providing a penalty for the violation thereof.

Be it enacted by the legislature of the State of Washington:

SECTION 1. It shall be unlawful for any person, firm, corporation, or company having possession or control of any artesian well within the State, whether as contractor, owner, lessee, agent, or manager, to allow or permit water to flow or escape from such well between the first day of October in any year and the first day of April next ensuing: *Provided*, That this act shall only apply to sections and communities wherein the use of water for the purpose of irrigation is necessary or customary, and providing further, that nothing herein contained shall prevent or prohibit the use of water from any such well between said first day of October and the first day of April next ensuing for household, stock, and domestic purposes only, water for said last-named purposes to be taken from such wells through a one-half inch stop and waste cock to be inserted in the piping of such well for that purpose.

SEC. 2. *It shall be the duty of* every person, firm, corporation, or company having possession

The reason why the owner of a well should be required by law to properly case it, as already explained in reference to the personal interest of the owner himself, is that lateral escape of the water may be prevented. The escape of water from an artesian basin in excess of the natural overflow means a decrease in pressure on the portions remaining, and consequently a lowering of the artesian head. In arid regions especially the sources of supply of an artesian basin may be small, and the question of economically using the water it contains and of maintaining the artesian head are matters of public concern.

2. *Every artesian well when not in use should be securely closed.*—The reason why a law to this effect should be enacted and enforced is that an artesian basin is not an inexhaustible reservoir, and every practicable means should be employed for its conservation and legitimate use. The closing of an artesian well when its water is not being used would in many and perhaps most instances be an advantage to its owner as well as to his neighbors, not only for the reason that his water supply would be made more permanent, but because water flowing over land in excess of the amount required for scientific irrigation is injurious.

There are exceptional cases in which it is not desirable that an artesian well should be closed at any time, as, for example, when a well is to prove that a developed spring, or derives its water from what is known as an artesian slope, but as such wells will probably be few in number in the artesian basins described in this report, special [illegible] reference to them is perhaps not desirable.

[illegible] of this act, to securely cap the same over
[illegible] every year in such manner as to prevent the
[illegible] the same securely capped and prevent the flow
[illegible] April next ensuing: *Provided, however*, It
[illegible] corporation, or company to insert a one-half
[illegible] well and to take and use water therefrom
[illegible] domestic purposes, but

[illegible] manager having possession or control
[illegible] shall be deemed guilty of a misdemeanor,
[illegible] exceeding two hundred dollars for
[illegible] hundred dollars for each ten days dur-

[illegible] party in possession or control of an
[illegible] person, firm, corpora-
[illegible] adjacent to or in the vicinity of
[illegible] upon the land upon which
[illegible] which water is allowed to flow or
[illegible] well and shut in and
[illegible] incurred in so doing
[illegible] land surrounding the same for
[illegible] action in any
[illegible] plaintiff a reason-
[illegible] addition to the penalty pre-

[illegible] the last of the act

Every abandoned drill hole in an artesian basin should be completely filled with impervious material.—A desirable way in which to his is to fill the hole slowly with moist clay and ram it down with eavy, blunt tool, or fill the hole with Portland cement concrete. htly fitting rods of dry wood driven into a drill hole until it is d would serve the same purpose.

bandoned wells should be filled in the manner suggested in order t leakage may be prevented. Wells in which water rises some ance toward the surface but does not overflow are frequently ndoned, the casing, if any was used, having first been drawn, and uch instances a continuous escape of water occurs into cracks, ous beds, etc., about the hole.

he three rules briefly stated above should be embodied in the laws very State in which artesian basins occur and their observance uld be rigorously enforced.

or the proper development of an artesian basin it is evident that e should be but one center of responsibility. A desirable method ecuring this end would be to place the entire control of the arte- wells in each State in the hands of a State engineer, whose duty hould be to determine where wells may be drilled, the depth to ch they may be carried, and methods for caring for the water sup- closing abandoned drill holes, etc.

While the aim of this preliminary report is to stimulate and direct search for artesian water in the region that has been considered, not wish to be understood as saying that all of the 2,000 or more are miles of rich lands contained in the four basins described can rrigated by means of artesian water. The facts are plainly such o warrant the careful testing of the artesian possibilities, but ng to local conditions, which are at present unknown, many dif- lties will no doubt be encountered and numerous failures may ır, and even when all the wells which the water supply will justify e been put down in any one of the basins referred to there will loubt remain extensive areas that can not be irrigated. While l results may reasonably be expected from the judicious develop- t of the artesian basins, all the benefits that might be derived in way will be rendered negative unless the suggestions given above eference to the conservation of the water supply are strictly rved. I may perhaps add as a warning that the wanton destruc- of the forests in this country and the now almost complete ruin he public grazing lands throughout the arid regions leave but lit- ope that man's greed will be so far restricted in the case of arte- basins that ultimate failures will be avoided.

LITERATURE.

The following-named books and papers contain information in reference to artesian wells which should be of much assistance to persons desiring to develop artesian basins:

1. BARBOUR, E. H. Wells and windmills in Nebraska: Water-Supply and Irrigation Paper U. S. Geol. Survey No. 29.
2. CARLL, J. F. Report on the oil regions of Pennsylvania: Second Geological Survey of Pennsylvania, Vol. III, 1880.
   This report contains a detailed account of the methods used in drilling wells.
3. CHAMBERLIN, T. C. The requisite and qualifying conditions of artesian wells Fifth Ann. Rept. U. S. Geol. Survey, pp. 125–173.
   This paper contains a clear and comprehensive explanation of the geologic conditions pertaining to artesian wells.
4. DARTON, N. H. Artesian-well prospects in the Atlantic Coastal Plain region Bull. U. S. Geol. Survey No. 138.
5. —— New developments in well boring and irrigation in eastern South Dakota Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, pp. 561–616.
6. —— Preliminary report on artesian waters of a portion of the Dakota Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 603–694.
7. —— Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, pp. 719–785.
8. —— Underground waters of southeastern Nebraska: Water-Supply and Irrigation Paper U. S. Geol. Survey No. 12.
9. GILBERT, G. K. The underground water of the Arkansas Valley in eastern Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 551–601
10. HAY, ROBERT. Water resources of a portion of the Great Plains: Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 535–588.
11. HILL, R. T., and VAUGHAN, T. W. Geology of portions of the Edwards Plateau and Rio Grande Plain adjacent to San Antonio, Tex., with special reference to the occurrence of artesian and other underground waters Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 193–322.
12. LANE, A. C. Water resources of the Lower Peninsula of Michigan: Water-Supply and Irrigation Paper U. S. Geol. Survey No. 30.
13. LEVERETT, FRANK. The water resources of Illinois: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, pp. 695–849.
14. —— Well waters of Ohio and Indiana: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, pp. 419–560.
15. —— Wells of northern Indiana: Water-Supply and Irrigation Paper U. S. Geol. Survey No. 21.
16. —— Wells of southern Indiana: Water-Supply and Irrigation Paper U. S. Geol. Survey No. 26.
17. ORTON, EDWARD. The rock waters of Ohio: Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, pp. 633–717.
18. —— The Trenton limestone as a source of petroleum and inflammable gas in Ohio and Indiana: Eighth Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 475–662.
19. PECKHAM, S. F. Report on the production, technology, and uses of petroleum and its products: Tenth Census of the United States, Vol. X, Washington 1888.
   The methods of drilling wells, together with detailed plans and descriptions of machinery, derricks, tools, torpedoes, etc., are given on pages 7 *to 85.*

20. PHINNEY, A. J. The natural-gas field of Indiana: Eleventh Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 579–742.

21. RUSSELL, I. C. Geology and water resources of Nez Perce County, Idaho: Water-Supply and Irrigation Paper U. S. Geol. Survey Nos. 53 and 54.

22. —— Geology and water resources of the Snake River Plains of Idaho: Bull. U. S. Geol. Survey No. 199.

23. —— A geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108.

24. SMITH, G. O. Geology and water resources of a portion of Yakima County, Wash.: Water-Supply and Irrigation Paper U. S. Geol. Survey No. 55.

25. TODD, JAMES EDWARD. Geology and water resources of a portion of southeastern South Dakota: Water-Supply and Irrigation Paper U. S. Geol. Survey No. 34.

26. VAUGHAN, T. W., and HILL, R. T. (See Hill.)

INDEX.

	Page.
posits, artesian wells in	44–45
example of	23
basin, conditions necessary for	10–14
ections of typical	13
asins, description of	24–44
ead, conditions controlling and manner of determining	12
rater, source of	13
indications of	14–15
rell, definition of	10
erry, Idaho, wells near	32–33
urrence and character of	19
reg., springs near	29
ho, springs near	27
ear	29–30
Valley, Idaho, springs in	27
n	30–31
k, Oreg., spring near	29
eg., springs near	39
ear	40–42
wells, necessity of	45–46, 47–48
daho, wells near	32–33
rature and depth of	35
rate, extent of	16
ch, Idaho, well on	29
urrence of	21
, size of	45
oned, necessity for filling	49
lls, in Harney artesian basin	40–43
ris artesian basin	29–37
nperature of, increase of, with depth	14
e, Idaho, spring near	27
ear	33–34
nperature and depth of	35
scription of	23
tesian basin, conditions of	10–14
criptions of	22–23
currence of	17
laho, wells near	32
nperature and depth of	35
reg., wells near	40
tesian basin, description of	38–43
s in	39–40
n	40–43
ake, Oregon, springs near	39
water in an artesian well, conditions controlling	12
g, Idaho, springs near	27
ch, Idaho, wells in	29
ocks, description of	18–21
conservation of artesian water, discussion of	47–49
esian basin, description of	24–37
l wells in	29–37
ard extension of	37
s in	28–29
on wells near Boise	29
W., cited on Payette formation	17
Literature, list of	50–51
Little Sage Hen Valley, Oregon, springs in	39
Little Valley, Idaho, springs in	27
wells in	31–32
Malheur Lake, Oregon, springs near	39
Malheur River, springs near	28
Mountain Home, Idaho, springs near	26–27
Newell, F. H., letter of transmittal by	7
Ontario, Oreg., wells near	34
Otis artesian basin, description of	37–38
Owyhee Canyon, Oregon, spring near	28
Payette formation, extent and character of	17
Pence, A. H., well of	31
Plutonic rocks, occurrence and character of	21
Poison Creek, Idaho, springs near	27–28
Pressure of water, conditions controlling and manner of determining	12
Rattlesnake Creek, Idaho, springs near	26–27
Rhyolite, occurrence and character of	20
Roberson's ranch, Idaho, well at	30–31
Rocks of region, classification and description of	16–21
Salmon River, Idaho, springs near	27
Sands, Idaho, springs near	27–28
Sandstones, extent of	16
Sedimentary rocks, description of	16–18
Silver Lake, Oregon, springs near	39
Springs, Harney artesian basin	39–40
Lewis artesian basin	26–29
warm, artesian conditions indicated by	14–15
Stein Mountain, Oregon, anticlines and synclines near	23
dikes on	21
Structure, description of	22–24
Syncline, example of	23
Temperature of the earth, increase of, with depth	14
Vale, Oreg., springs near	28
wells near	34
Volcanic dust, occurrence of	17
Volcanic rocks, description of	18–21
Walters Butte, Idaho, springs near	27
Warm springs, artesian conditions indicated by	14–15
Water, artesian, height of, conditions controlling	12
source of	13
surface indications of	14–15
Well, artesian, definition of	10
Wells, artesian, closing of, necessity for	48
Wells, drilled, in Harney artesian basin	40–44
in Lewis artesian basin	29–37
Well records, preservation of	46–47
Westfall, Oreg., springs near	28–29
Whitehorse artesian basin, description of	43–44
Whitson's ranch, Idaho, well at	31

O

upply and Irrigation Paper No. 79 Series L, Quality of Water, 5

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

;MAL AND POLLUTED WATERS

IN

NORTHEASTERN UNITED STATES

BY

MARSHALL ORA LEIGHTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

Water-Supply and Irrigation Paper No. 79 Series L, Quality of Water, 5

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

NORMAL AND POLLUTED WATERS

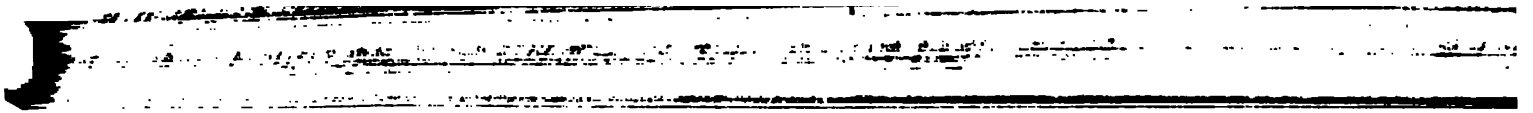
IN

NORTHEASTERN UNITED STATES

BY

MARSHALL ORA LEIGHTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903



CONTENTS.

	Page.
Letter of transmittal	11
Introduction	13
Essential qualities of water for various uses	13
Impurities in natural waters	16
Rain water	16
Surface waters	17
Underground waters	21
Sanitary analyses	22
Pollution of natural waters	31
Merrimac River Basin	33
General features and methods of utilization	33
Flow measurements	36
Character of normal water in the Merrimac Basin	37
Pollution in the Merrimac Basin	38
Shawsheen River	38
Concord River	39
Sudbury River	40
Assabet River	44
Concord River between Concord and Lowell	45
Nashua River	46
South Branch	47
North Branch	50
Other tributaries of the Merrimac	54
Pollution of Merrimac River at Manchester, Nashua, Lowell, Lawrence, and Haverhill	55
Blackstone River	60
Course, character, and utilization of the stream	60
Population of the basin	60
Normal water in basin of the Blackstone	62
Pollution in Blackstone River	63
Connecticut River Basin	68
Natural resources	68
Flow	71
Millers River	73
Normal water	74
Pollution	75
Deerfield River	76
Chicopee River	77
Ware River	80
Swift River	82
Quaboag River	83
Westfield River	85
Hockanum River	89
Park River	91
Farmington River	94
Connecticut River	94

Page.
Housatonic River ... 98
Natural resources ... 98
Normal water ... 100
Pollution ... 101
Court decisions in Connecticut ... 107
Delaware River ... 112
Ohio River Basin ... 115
Drainage area ... 116
Character of water ... 118
Allegheny River ... 119
General features ... 119
Population of basin ... 120
Pollution ... 121
Character of water ... 122
Monongahela River ... 124
Mahoning River ... 129
Natural resources ... 129
Character of water ... 130
Muskingum River ... 136
Walhonding Creek ... 136
Black Fork ... 137
Rocky Fork ... 139
Jerome Fork ... 140
Mohican River ... 140
Owl Creek ... 141
Killbuck Creek ... 141
Tuscarawas River ... 142
Highland tributaries ... 143
Sandy Creek ... 144
Nimishillen Creek ... 144
Tuscarawas at Canal Dover and New Philadelphia ... 145
Stillwater Creek ... 146
Muskingum River below Coshocton ... 147
Wills Creek ... 148
Licking Creek ... 149
Scioto River ... 153
Drainage basin ... 153
Normal water in basin ... 154
Pollution in basin ... 155
Olentangy River ... 158
Ohio River at Cincinnati ... 162
Miami and Little Miami rivers ... 171
Little Miami River ... 171
East Fork of Little Miami River ... 176
Miami River ... 177
Normal water in Miami Basin ... 178
Mad River ... 179
Upper Miami River ... 180
Stillwater River ... 181
Miami River below Dayton ... 183
Ohio River at Louisville ... 184
Summary ... 187

ILLUSTRATIONS.

		Page.
FIG. 1.	**Normal chlorine map of Massachusetts and Connecticut**	28
2.	**Merrimac River drainage basin**	34
3.	**Concord River drainage basin**	40
4.	**Sudbury River drainage basin**	41
5.	**Nashua River drainage basin**	46
6.	**Blackstone River drainage basin**	61
7.	**Connecticut River drainage basin**	69
8.	**Millers River drainage basin**	73
9.	**Chicopee River drainage basin**	78
10.	**Westfield River drainage basin**	86
11.	**Housatonic River drainage basin**	99
12.	**Delaware River drainage basin**	113
13.	**Allegheny River drainage basin**	120
14.	**Monongahela River drainage basin**	125
15.	**Mahoning River drainage basin**	130
16.	**Muskingum River drainage basin**	137
17.	**Drainage basins of Miami and Little Miami rivers**	172

TABLES.

		Page.
1.	Analysis of a normal water from Massachusetts	23
2.	Analyses of a normal and a polluted water from Massachusetts	25
3.	Analyses of normal and polluted waters	29
4.	Utilized horsepower of tributaries of Merrimac River	35
5.	Estimated annual discharge of Merrimac River at Lawrence, Mass	36
6.	Mean flow of Sudbury River in cubic feet per second, 1875–1900	36
7.	Analyses of normal surface waters in Merrimac Basin	37
8.	Analyses of normal ground waters in Merrimac Basin	38
9.	Analyses of water from Shawsheen River	39
10.	Analyses of water from Sudbury River between Saxonville and Wayland	43
11.	Analyses of water from Sudbury River between Wayland and Concord	43
12.	Analyses of water from Assabet River	45
13.	Analyses of water taken at different points along Concord River	45
14.	Analyses of water from Quinepoxet and Stillwater rivers	48
15.	Analyses of water from Coachlace Brook	49
16.	Analyses of water from South Branch of Nashua River above its confluence with North Branch at Lancaster	49
17.	Analysis of water from Ashburnham storage reservoir	50
18.	Analyses of water from North Branch of Nashua River above Fitchburg	50
19.	Analyses of water from North Branch of Nashua River below Fitchburg	51
20.	Average of ten analyses of water from Monoosnoc Brook	51
21.	Analyses of water from North Branch of Nashua River, above its confluence with South Branch at Lancaster	52
22.	Analyses of water from Nashua River at Groton and Pepperell	53
23.	Average of nineteen analyses of water from Nashua River at Mine Falls	54
24.	Analysis of water from Pemigewasset River at Campton, N. H	55
25.	Average of nineteen analyses of water from Merrimac River at Nashua	55
26.	Analyses of water from Merrimac River above Lowell	56
27.	Analyses of water from Merrimac River above Lawrence	57
28.	Analyses of effluent of the Lawrence filter	58
29.	Increase in the amount of impurities in Merrimac River water, from a point above Lowell to Lawrence, as determined by regular monthly examinations in different years	58
30.	Analyses of Merrimac River water above Haverhill	59
31.	Analyses of Merrimac River water below Haverhill	59
32.	Population in drainage basin of Blackstone River	61
33.	Analyses of normal water in the Blackstone Basin	62
34.	Analyses of water from Blackstone River below mouth of Mill Brook and above outlet of sewage works	63
35.	Analyses of water from Blackstone River below Worcester sewage disposal outlet	65

Page.
36. Analyses of water from Blackstone River at Uxbridge 66
37. Analyses of water from Blackstone River at Millville 67
38. Analyses of water from Blackstone River at Albion and Valley Falls, R. I 68
39. Fall of Connecticut River 70
40. Drainage area and utilized horsepower on Connecticut River tributaries. 71
41. Flow of the Connecticut River at Holyoke during the years 1880–1898.. 71
42. Analyses of normal water in Millers River drainage area 74
43. Analyses of water from Millers River above Athol 75
44. Analyses of water from Millers River below Orange 76
45. Analyses of water from Deerfield River at various points 77
46. Principal ponds in basin of Chicopee River 78
47. Analyses of water from Ware River at Coldbrook station, Barre 80
48. Analyses of water from Musquapog Lake 81
49. Analyses of water from reservoir of Barre Water Company 81
50. Analyses of water from Ware River below Ware 82
51. Analyses of water from Swift River at designated points 83
52. Analyses of unpolluted water in Quaboag Basin 83
53. Analyses of water from Quaboag River above Palmer 84
54. Analyses of water from Quaboag River below Palmer 84
55. Analyses of water from Chicopee River below Ludlow 85
56. Analyses of normal water in the Westfield River system 87
57. Analyses of water from Westfield River above and below Westfield 88
58. Analyses of water from Shenipsit Lake 89
59. Analyses of water from Taylor's reservoir, Manchester, Conn 90
60. Analyses of water from Hockanum River at Windermere, North Manchester, and Burnside 90
61. Analyses of water from Pipers Brook and Park River 92
62. Analyses of water from Connecticut River at Northfield Farms 95
63. Average of 21 analyses of water from Connecticut River at Turners Falls 95
64. Analyses of water from Connecticut River at Northampton 95
65. Analyses of water from Connecticut River below Springfield 96
66. Analyses of water from Connecticut River at Warehouse Point, Rocky Hill, and Goodspeed Landing 97
67. Table showing fall in the Housatonic River 98
68. Analyses of the various normal waters in the Housatonic drainage area. 100
69. Analyses of water from East Branch of Housatonic River above Pittsfield. 101
70. Analyses of water from East Branch of Housatonic River at Pittsfield . 101
71. Analyses of water from West Branch of Housatonic River at Pittsfield. 102
72. Analyses of water from Southwest Branch of Housatonic River at Pittsfield 102
73. Analyses of water from Housatonic River at New Lenox 103
74. Analyses of water from Housatonic River at Stockbridge 104
75. Analyses of water from Housatonic River at Sheffield 104
76. Analyses of water from Housatonic River at Falls Village, Conn 105
77. Analyses of water from Housatonic River at Derby 106
78. Cities and towns above Trenton contributing polluting substances to Delaware River 114
79. Analyses of water of Delaware River at Trenton 115
80. Turbidity of Delaware River at Trenton 116
81. Comparison of analyses of normal waters in New England and in the Ohio Basin 118

Page.
2. Cities and towns on Allegheny River and tributaries above Pittsburg. 121
3. Analyses of water from Allegheny River at Brilliant, above Pittsburg 123
4. Mineral analysis of water from Allegheny River 123
5. Analyses of water from Allegheny River at Etna and Millvale 124
6. Cities and towns on Monongahela River and tributaries above Pittsburg 126
7. Analyses of water from Indian Creek and vicinity 127
8. Analyses of water from Monongahela River at Pittsburg 127
9. Analyses of water from Mahoning River above Alliance 131
10. Rainfall at Akron, Ohio 131
11. Analyses of water from Mahoning River below Alliance 132
12. Analyses of water from Mahoning River above Warren 133
13. Analyses of water from Mahoning River below Warren 133
14. Analyses of water from Mahoning River below Niles 134
15. Analyses of water from Mahoning River above Youngstown 135
16. Analyses of water from Mahoning River below Youngstown 135
17. Analyses of water from Black Fork above Shelby 138
18. Analyses of water from Black Fork below Shelby 139
19. Analyses of water from Rocky Fork above and below Mansfield 140
20. Analyses of water from Owl Creek above and below Mount Vernon 141
21. Analyses of water from Apple and Killbuck creeks above Wooster, and Killbuck Creek below Wooster 142
22. Analyses of water from Tuscarawas River above and below Massillon 143
23. Analyses of water from Nimishillen Creek above and below Canton 144
24. Analyses of water from Tuscarawas River above Canal Dover and below New Philadelphia 145
25. Analyses of water from Big Stillwater Creek above Uhrichsville and below Uhrichsville and Dennison 147
26. Analyses of water from Walhonding Creek, Tuscarawas River above Coshocton, and Muskingum River below Coshocton 148
27. Analyses of water from Wills Creek above and below Cambridge 149
28. Analyses of water from Licking Creek above and below Newark 150
29. Analyses of water from Muskingum River and Licking Creek above and below Zanesville 150
30. Analyses of water from Muskingum River above McConnelsville 152
31. Analyses of water from Muskingum River above Marietta 152
32. Drainage area of the Scioto River and tributaries 154
33. Analyses of water from Scioto River above Kenton 155
34. Analyses of water from Scioto River below Kenton 155
35. Analyses of water from Little Scioto River above and below Marion 156
36. Analyses of water from Scioto River above and below Ohio Girls' Industrial Home 156
37. Analyses of water from Scioto River above and below Wyandot Grove 157
38. Analyses of water from Scioto River at Jones's dam 157
39. Analyses of water from Scioto River at Sandusky street bridge 158
40. Analyses of water from Olentangy River above and below Galion 158
41. Analyses of water from Olentangy River above and below Delaware 159
42. Analyses of water from Olentangy River at Olentangy Park 159
43. Analyses of water from Olentangy River at Dublin bridge, Columbus 160
44. Analyses of water from Scioto River at Frank road bridge, Columbus 161
45. Analyses of water from Scioto River at Shadeville bridge 161
46. Analyses of water from Scioto River at Circleville 162
47. Turbidity of Ohio River water 163

Page.

128. Periods of subsidence necessary with water from Ohio River at Louisville, Ky 163
129. Table showing monthly rainfall, in inches, at various stations in Ohio Valley for the year 1898 164
130. Table showing normal rainfall, in inches, at various stations in Ohio Valley 165
131. Number of days in the year on which the Ohio River was rising at various rates during the last ten years 166
132. Summary of the amounts of several constituents found in water of Ohio River for the year 1898 166
133. Suspended matter in Ohio River at Cincinnati from January 10 to March 23, 1898, with corresponding stages of river in feet 169
134. Results of tests for *Bacillus coli communis* in Ohio River water at Cincinnati 170
135. Analyses of water from Little Miami River above South Charleston 173
136. Analyses of water from Little Miami River above Xenia 174
137. Analyses of water from Little Miami River below Xenia 175
138. Analyses of water from Little Miami River above Loveland 175
139. Analyses of water from East Fork of Little Miami River above Batavia 176
140. Analyses of water from East Fork of Little Miami River below Batavia 176
141. Analyses of water from Little Miami River below Linwood 177
142. Analyses of nearly normal waters in Great Miami River Basin 178
143. Analyses of water from Mad River 180
144. Analyses of water from Upper Miami 181
145. Analyses of water from Stillwater River 182
146. Analyses of water from Miami River 183
147. Amount of carbonic acid gas dissolved in the Ohio River water at Louisville 185
148. Amount of normal hardness in water of Ohio River at Louisville 186

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., November 13, 1902.

SIR: I have the honor to transmit herewith a manuscript entitled "Normal and polluted waters in Northeastern United States," prepared by Marshall O. Leighton, resident hydrographer, United States Geological Survey, and to request that it be published as one of the series of Water-Supply and Irrigation Papers.

This paper is principally a review of the more readily available records, published and unpublished, of examinations made of water supplies derived from streams in the northeastern part of the United States, the principal streams examined being the Merrimac, Connecticut, Housatonic, Delaware, and Ohio rivers, and the various important branches of the latter in the States of Pennsylvania and Ohio. It is, in effect, an account of the important work done in river examination up to the present date, a few unfinished inquiries now in progress being omitted.

The introduction treats of the characteristics of normal and polluted waters in general and seeks to explain, in language intelligible to those not versed in chemistry, the meaning and importance of the various determinations made in an ordinary water analysis. In dealing with the various rivers which have been subjected to examination, wherever the courts have been invoked to pass upon the legality of any existing state of pollution, or to adjust damages occasioned thereby, the cases are cited and pertinent excerpts are given from the decisions.

This paper forms one of a series of reports on examinations made as to the character of the natural waters of the United States and the pecuniary damage to municipal water supply occasioned by city and industrial wastes. It is expected that examinations of like nature will be undertaken by the Survey in cooperation with the various universities and State laboratories in the country, the character of the work differing according to the conditions and demands in each case.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey,
Washington, D. C.

NORMAL AND POLLUTED WATERS IN NORTH-EASTERN UNITED STATES.

By M. O. LEIGHTON.

INTRODUCTION.

In order to properly determine the water resources of a country, nd to define the limitations of use which apply to various rivers, it ecomes necessary to know the character of the water in each case. Vater is a source of wealth by reason of the uses to which it may be it, and these are dependent to a large extent upon the nature of ie water. It follows, then, that for each branch of water utilization iere is established a standard to which water must reasonably con-rm, in order that it may properly fulfill the requirements of the irticular case.

By reason of their physical features and their artificial develop-ent, different rivers may possess characteristics which make them ry different in their form or kind of utility. Sewage pollution may stroy every resource of one river, yet may not sensibly affect the lue of another. One stream may be highly useful as a source of wer; another may be best utilized primarily as a commercial high-ay; still another may serve as a source of water supply. There are aters which are more valuable as a disposal area for manufacturing fuse than they would be if maintained unpolluted as fishing grounds ice fields. Therefore a thorough hydrographic investigation should rve to indicate the peculiar uses to which a stream is best appli-ble, and by it we should be able to determine the normal resource each case and the damage done by unwise or unlawful procedure. especial importance is the fact that the utilization of a river in ie State may be so damaging to its purity that the people of another tate through which the same river flows may be totally deprived of s use, and, under present conditions, with little if any opportunity r redress.

Let us glance briefly at the characteristics that are demanded of aters required for different uses.

ESSENTIAL QUALITIES OF WATER FOR VARIOUS USES.

Commercial highways.—The character of a water has nothing to o with its use as *a means* of transportation. For this purpose it is

only necessary that it shall be sufficient in amount to float vessels and that the course in which it runs shall be deep and broad and uninterrupted by impassable obstructions.

Power.—For utilization as a source of power a stream should have sufficient grade to allow the conservation of large quantities of water behind dams, so that it may be forcibly delivered upon water wheels, and, by means of the power developed by this impact, may operate mechanism applied to human purposes. If the gradient is abrupt—that is, if it is largely concentrated in one or several places, so that the water falls over precipices or runs in rapids—the power available will be greater and the expense of development will be less than if the fall of the stream is gentler or the stretches between rapids are longer. The constituents of a water used for the development of power are not of great importance except in such cases as its impounding by dams may be the means of holding back or depositing accumulated impurities which become a source of discomfort and thereby depreciate the value of real estate.

Manufacturing.—It is essential that a water used in manufacturing processes shall not contain anything which, from a chemical or sanitary standpoint, shall be injurious to the products of manufacture. The manufacturing uses to which water is put are very numerous, and when it is to become one of the constituent parts of the product it is necessary, in most cases, that it shall be pure and not liable to damage the product by reason of any substances which it may carry in solution or suspension. If, on the other hand, it is intended that the water shall be employed merely in the process of manufacture, as in washing products or in dissolving ingredients, it is readily apparent that foreign substances in the water may defeat this purpose.

Use in boilers.—Normal or pure water has a certain action upon metals, iron being one of those easily affected. If, therefore, a pure water is used in a boiler there must necessarily be some action which has its part in shortening the term of usefulness of the boiler. When a water is used which contains ingredients that hasten this action upon iron or which deposits sediments within the boiler, the usefulness of the boiler is shortened unduly, and the value of the water as a boiler water is lessened by an equivalent amount. An idea of the damage done by calcareous matter in water, which is deposited as an incrustation within the boiler, can be formed by considering the experience of the engineers on the Nebraska Division of the Union Pacific Railroad, where the water used held in solution a large quantity of sulphate of lime and magnesia. When such water is boiled the sulphate is deposited on the inside of the container. The expense of cleaning and repairing boilers by reason of this deposit amounted in two years to $2,860, equal to 8 cents per mile of distance run. In addition to this the total mileage of each engine was probably reduced *one-half*

Fisheries.—It requires only a slight study of the subject of fresh-water fisheries to appreciate how acute is the effect of water pollution upon the living organism. Many waters in the United States that were once good fishing grounds have, within recent years, become destitute of fish because of the dumping of wastes from factories or public sewers into lakes or rivers.

Nuclei of parks.—The development of park systems in this country is a striking revelation of a growing civilization. That there should be recognized, in this highly commercial atmosphere, the need of establishing pleasant places of rest, where the careworn citizen may escape for a short season from his business encumbrances, is a cause for gratification. No one has properly estimated the value of these shelters to the workingman, the isolated housewife, or the dust-stifled child. It is fast becoming the conviction of popular representatives that the people have a right to retain unto themselves certain convenient portions of the country in its natural state. Of such there could be many within easy reach of every city, but too often their establishment is made impossible by the foulness of the water flowing past available sites or standing close by in natural reservoirs. A body of pure water is the proper nucleus of such a place, for bathing, boating, fishing, and pleasant atmosphere are all necessary accompaniments of the perfect park. But in a place where bathing becomes suicide, boating resembles a voyage with Charon, and even breathing taxes the strong stomach, there is little prospect that a park will be established.

Ice supply.—The requirements of a water to be used as a source of ice supply closely resemble those hereinafter described with reference to water supply. The difference lies in the fact that a large proportion of foreign matter in water is excluded upon the formation of ice. Just how much is yet uncertain, but the most recent investigations show that the microorganisms which produce disease do not live long in ice.

Irrigation.—Water used for purposes of irrigation must contain none of the various mineral impurities, such as those found in manufacturing wastes, which are known to have a deleterious effect upon vegetation. This danger to irrigation is so remote as to be unworthy of a passing remark. Irrigation districts are not, and probably never will be, manufacturing ones.

Drinking water.—The standards set for a drinking water are more precise than those prescribed in any other branch of water utilization. Water is necessary to the continuance or even the existence of life, powerfully affecting human beings for better or for worse according to its character, and as the immediate preservation of human life is the principal object of society, this phase of the water question is more important than all those previously discussed.

It is not necessary that a water for public supply shall be chemically pure; indeed, such a water would be in many ways undesirable. Generally speaking, that which flows off or out of the land in its

natural state is usually well suited to the needs of man. If, however, in flowing out of a drainage area it becomes contaminated with the ejecta of man or of domestic animals; if into the courses in which it flows there is emptied the refuse from mills and factories; if upon the land drained by the stream there has been spread any animal refuse whatsoever, then the run-off water will be changed in character, and even though it may subsequently be treated, naturally or artificially, in such a manner that it is not prejudicial to health, it will bear to its final destination the marks of its former bad associations.

The value of a water is commonly reckoned according to its availability for public consumption. To be acceptable to the public it must have little or no turbidity and must contain little or no sediment or organic waste, color, taste, or odor. It will, therefore, be useful to follow the course of a quantity of water from its source in the ocean around its cycle of changes until it again reaches the ocean, in order to show how great are the obstacles that prevent it from meeting these several requirements.

IMPURITIES IN NATURAL WATERS.

RAIN WATER.

Water is raised by evaporation from oceans, lakes, ponds, and from the surface of the earth, and carried aloft, there to float in the form of clouds until the air sustaining it is saturated, when it is condensed and precipitated upon the earth. In falling through the air rain water naturally washes out any impurities held there in suspension. These impurities consist of dust composed of organic and mineral matter, such as pulverized earth, soot, pollen, and dried and finely divided particles of plants and insects, as well as ammonia, carbon dioxide, sulphuric acid and other gases, all of which are dissolved or held in suspension by water. Consequently when the rain strikes the earth it is not, as is commonly supposed, pure water. The amount of impurities it may contain depends on local conditions. If the air washed is that lying over a large manufacturing city it is manifest that the water on reaching the earth will be less pure than that falling upon a primeval region. Nevertheless, even in the latter case, the air always contains a certain amount of foreign matter. It is also manifest that rain water falling during the later part of a storm will be purer than that which first fell, for after a time the air will be cleared of its impurities.

On striking the earth, assuming that it falls on a mountain or on sloping land, there are several courses that water may take. Some of it is immediately absorbed by vegetation or directly evaporated from the earth's surface as it was from the ocean. The larger part, however, takes two other courses: (1) It runs directly off the surface in rivulets, converging into rills, streams, brooks, and rivers; (2) it sinks into the earth and, after filtering to a greater or less depth, re*appears as springs* or is intercepted by wells. Let us first follow that *which runs directly* along the surface of the earth.

SURFACE WATERS.

Some of the impurities which the water gathered in the air are lost as soon as it comes in contact with the earth, but in its course along the surface many more are gathered up—particles of sand or silt; pieces of dried or decayed leaves, wood, and grass; microscopic insects, and myriads of bits of other material of an almost imponderable nature which in the aggregate amount to a surprisingly large quantity. These particles ultimately are dissolved, or if sufficient time is not afforded to dissolve them they are deposited on the bottom of the stream in places where the current of the stream is checked. We have, therefore, the following classification of impurities in water:

Impurities in water.

- 1. Suspended matter
  - Inorganic or mineral: Sand, clay, and various pulverized minerals.
  - Organic
    - Animal: Living microscopic animals, dead fish and pieces thereof, feathers from birds, etc.; decayed animal refuse; manufacturing wastes, such as wool scourings, blood from slaughterhouses, etc.; excrement from sewers, etc.
    - Vegetable: Dried leaves, grass, and flowers, decayed wood, peaty matter; algæ and other plant life, including bacteria; wastes from cotton, silk, and linen mills, and from distilleries, etc.
- 2. Dissolved matter
  - Gaseous
    - Carbon dioxide.
    - Hydrogen disulphide.
  - Solid
    - Inorganic metals in general.
    - Organic
      - Animal (see above).
      - Vegetable (see above).

Organic matter.—Water as it passes over the earth, therefore, becomes more and more impure, the extent of its pollution depending on the character of the matter which it gathers up and carries along or which is poured into it by artificial means. Matter which is merely held in suspension would not seriously affect the character of water but for the phenomenon of solution, by reason of which the state of suspension is not permanent, for sooner or later a large part of the suspended matter is dissolved. It is a familiar sight to see inorganic matter dissolve in water, and the process seems simple; but the explanation of the solution of organic matter presents difficulties. How is it brought about? In order to explain this it will be necessary to discuss briefly the composition of organic matter.

Organic matter—that is, matter which is the product of life processes—consists chiefly of the four elements, carbon, oxygen, hydrogen, and nitrogen. These elements stand closely in union as long as life endures. Immediately upon the occurrence of death, however, there comes a breaking down. The chemical combination in the original living matter may be expressed thus:

Oxygen—Carbon
| × |
Hydrogen—Nitrogen.

When there is no longer a bond of union between the four elements there comes dissociation and a reuniting of elements having attraction one for the other. In this case one of the first steps in the breaking down of the above combination may be expressed as follows:

$$\frac{\text{Oxygen—Carbon}}{\text{Nitrogen—Hydrogen.}}$$

The oxygen in this and in the other processes here described is derived to only a limited extent from the decaying organic matter itself, but is drawn in large part from the atmosphere and from the store of oxygen suspended in the water. The oxygen and carbon combination, known as carbon dioxide or popularly as "carbonic acid," combines with other elements or goes into solution as such, and its connection with the old combination is permanently severed. The nitrogen and hydrogen combine and form ammonia. This completes the first step in the process. We have the organic matter, once in suspension, then in solution, now broken up into two very familiar compounds, both inorganic.

The process is not yet finished. The combination, nitrogen-hydrogen, is not a strong one. It is easily disturbed in several ways, and one of these is the introduction of more oxygen, which is nearly always present in water and always in air and in innumerable chemical combinations. Both of the above elements are more strongly attracted by oxygen than they are by each other, and therefore there is a further breaking up. The next step may be represented as follows:

$$\frac{\text{Nitrogen—Oxygen—Hydrogen}}{\text{Hydrogen—Oxygen.}}$$

Now the hydrogen-oxygen combination is water, a very stable compound, and therefore that portion of the hydrogen and oxygen which is combined as indicated in the diagram is permanently disposed of. No further change takes place in it. Not so with the nitrogen-oxygen-hydrogen. As it is first combined, one part of nitrogen and one part of hydrogen, hold together two parts of oxygen, so that the combination is more accurately expressed:

$$\text{Nitrogen} \begin{cases} \text{Oxygen—Hydrogen.} \\ \text{Oxygen.} \end{cases}$$

This combination would remain stable if there were not more oxygen present and available. But as the element nitrogen can hold in combination three parts of oxygen, there can be no permanent chemical compound formed until this possibility is accomplished; so another change takes place, and the nitrogen finally holds three parts of oxygen, thus:

$$\text{Nitrogen} \begin{cases} \text{Oxygen—Hydrogen.} \\ \text{Oxygen.} \\ \text{Oxygen.} \end{cases}$$

The first compound is one of the substances that are necessary to the formation of a nitrite; the second forms the foundation for a nitrate, the essential distinction between these consisting of a difference in the amount of oxygen present. A nitrite represents a very unstable, transitory combination, which takes place in the oxidation of organic matter, and which in any case is not permanent. A nitrate, however, represents the final condition of mineralized organic matter. It is the stage where the decay of that which was formerly living matter stops, when every chemical demand is satisfied. A nitrate is a permanent, stable compound which is not readily broken up nor acted on by other elements or compounds.

It must be remembered that the changes above described, as will hereafter be noted more fully, take place in the presence and by the action of living organisms, and while the processes roughly outlined are not so simple as has been indicated, the foregoing explanation will nevertheless, it is hoped, give a general idea of their character. As a concluding remark, it is sufficient to note that under the circumstances the condition of nitrogen in a water faithfully represents the condition of the organic matter in that water.

Bacteria.—Having traced the changes that take place in the organic matter of a surface water, let us now consider the means by which such changes are effected. In the list of organic materials above enumerated it will be remembered that bacteria found a place among those matters "suspended." It is by their agency that the changes above described take place. They are not the bacteria which are known to produce disease, but they belong to the great and useful species of the order. They are found primarily in the air and in the ground, and their presence is indispensable to the reduction of waste organic matters to the inorganic elements from which they are made up. Along with the pollen, the soot, and the fine particles of animal and vegetable matters in the air, these bacteria are collected by the rain falling to the earth. When they are brought to the earth in rainfall they immediately begin the work of changing the organic matter, and they are at once reenforced by the myriads which are always present in the ground. The greater the amount of organic matter carried along by the water, the greater the number of bacteria that gather to reduce it, so that the number of bacteria found in a water is an accurate measure of the amount of organic matter it contains. Their presence in large amount does not necessarily signify that the organic matter is dangerous, but the very fact that there is sufficient food to sustain great numbers of bacteria is sufficient indication that putrefactive processes are going on in the water, the true significance of which must be ascertained before the water should be accepted for domestic use. Animal matter is more highly putrefactive than vegetable matter, and, except under extraordinary conditions, a high number of bacteria is indicative of animal pollution.

Algæ.—There is another great branch of the plant kingdom which exerts a powerful influence upon the purification of surface waters: This is the group Algæ. These are the minute green plants which, in stagnant pools, grow in such large numbers as to occasionally form what is popularly known as a "scum" over the surface. These plants subsist upon the products of decomposition of organic matter. As soon as the bacteria succeed in breaking down the complex organic combination as above described, these algæ grow abundantly and feed upon the products of decomposition. As the change from ammonia to nitrites and nitrates is made, they continue to consume the débris, so that the tendency is to clear the water of such matter. If such a water were placed in a glass and no further pollution were allowed to enter, it would be found that after a short period the ammonia, nitrites, and nitrates would be greatly reduced. It is also true that the algæ themselves live to maturity and die, contributing more organic matter to the water. But, unless the conditions are such that an overabundant growth is induced, and the living algæ can not consume the débris of their dead ancestors, the supply of organic matter from this source is not such as to materially affect the condition of the water from the standpoint of total organic nitrogen.

These algæ ofttimes contribute odors, tastes, and color to the water as a result of their life processes and their decay, so that in all cases their presence is not wholly beneficial from a sanitary standpoint. Such odors and tastes are characteristic and can be readily detected. The action of algæ described above is not fully exerted unless the water is quiet, or practically so, for a short time, although there is no doubt that some action takes place in running streams.

Algæ also feed upon carbon dioxide set free by the action of bacteria upon organic matter. The recent studies along this line are very instructive, and seem to clear up an important point which has, for a long time, not been fully understood. The purifying process which has been supposed to exist in the extensive aeration of water, like that tumbling down over a cataract, has been found to have very little effect upon the state of organic matter in the water. Dr. Thomas M. Drown, in a memorable experiment, found that after air had been blown through water for an extended period very little change had resulted in the condition of the organic matter. The work served to emphasize the fact that bacteria are all important in the oxidation of organic matter, and that the process is distinctly different from the oxidation of an inert mineral substance. It was therefore believed that the splashing of a brook down the side of a mountain had no purifying effect. Recent work has shown, however, that this process is beneficial, not on account of the absorption of oxygen in the water, but by reason of the expulsion of the carbon dioxide from it, so that the algæ, deprived of a large part of their *food, would not* be likely to grow to an extent that would make their *presence objectionable.*

Disease germs.—There is one other requirement demanded of a drinking water which, although inseparably linked with much that has gone before, must nevertheless be treated by itself. This requirement is, that a water used for domestic purposes shall not contain the specific germs or bacteria of ground-borne diseases, such as typhoid fever and cholera. It has been stated that in all waters in which the decomposition of organic matter is going on there are bacteria, which are requisite to the furtherance of this decomposition. It has also been shown that, although these bacteria are not productive of any specific disease, their presence in large numbers in a given water is a satisfactory indication that there must be a correspondingly large amount of decaying matter in the water to provide them sustenance. Experience has shown that a water which during a long series of examinations shows an average of more than 150 to 200 bacteria per cubic centimeter merits careful investigation. The presence of disease-producing bacteria is a matter which requires special consideration.

The bacterium commonly occurring in the United States is the bacillus of typhoid fever. This disease has its seat in the human intestine, and the infective material is naturally ejected during the course of the disease, and is carried along through sewers to the place of disposal. If this is a river the water therein becomes infected with germs of this disease, and the infection is communicated to persons drinking the water farther down the course. It is well known that the natural habitat of these bacteria is not in water, and therefore their life is not continued for a long period. Just how long this period is, however, is very uncertain; it surely has no connection with the period required to mineralize organic matter. Therefore the absence of the latter in its unoxidized state is no guaranty that dangerous bacteria are not absent. Their term of life probably varies widely, depending upon the local conditions, temporary or permanent.

UNDERGROUND WATERS.

Heretofore we have considered only that part of the water of precipitation which, upon striking the earth, flows directly off the surface into streams. That part which sinks into the ground is of equal importance, for it constitutes the reserve supply from which streams are replenished after the influx due to a rainfall has spent itself. All ground waters must at some time issue from the ground in the form of springs, wells, etc., and, flowing along in courses, become surface waters.

Basis of interpretation.—The fitness of ground water for public supply must be determined in ways very different from those used in determining the potability of surface waters. When rain water sinks into the earth it meets conditions which are highly favorable to the oxidation of the organic matter it contains. The water sinks slowly down through the particles of sand, the faces of which are covered

with the bacteria that bring about oxidation. Under such conditions an enormous extent of bacterial surface is exposed to the water, and the change of the organic matter from albuminoid ammonia to nitrates is exceedingly rapid and complete. Consequently, when such water emerges from the ground it is to be expected that the amount of ammonia and nitrates will be exceedingly small or absolutely wanting. When a spring water is found which possesses these ingredients, it is practically certain either that the water was originally a surface water which, upon entering the earth, has quickly passed below the layer of available oxygen in the ground, so that the normal process of decay has been retarded, or, having been once freed from its organic matter, has become contaminated with the contents of some sewer, cesspool, drain, or other source of waste matter. It is not an easy task to discriminate between these two possibilities unless there is at the disposal of the investigator a table or chart showing the amount of normal chlorine of the water of the locality within which the spring is located. With such information at hand, it is necessary only to compare the amount of chlorine found with the normal amount for the locality to ascertain whether the contamination is local or arises from natural phenomena. It has therefore become the practice of sanitarians to demand that a ground water shall contain little or no unoxidized organic matter. The amount of nitrates found in such a water is nearly always large, sometimes rising, in perfectly safe waters, to a very high proportion. Such results indicate an extensive previous pollution, which has been thoroughly cleared up. The element of danger in waters of this kind is the possibility that there might at some time be such a change in conditions controlling this oxidation that the process would fail of completeness.

Storage of ground waters.—When ground waters are stored in reservoirs in the presence of sunlight there is a quick and profuse growth of algæ in the basin, due to the abundant presence of nitrates which serve for food. Under such circumstances it is necessary to cover the reservoirs when it is desired to preserve ground waters in their original state.

SANITARY ANALYSES.

It will now be instructive to consider sanitary analyses and their significance. A sanitary analysis of water is not the determination of its mineral constituents and the quantity of each, but consists of the observation of a few physical characteristics, such as color, turbidity, odor, etc., and a determination of the different forms of nitrogen it contains, the amount of which, as has been remarked, is a faithful representative of the character of the organic matter in the water. It should be distinctly borne in mind that the ingredients which are determined in such an analysis are not harmful of themselves, *and, as such,* have no significance whatever. They are simply

guideboards which point out the way to a knowledge of the true condition of the water.

In Table 1 is given an analysis of a normal water in the State of Massachusetts.

TABLE 1.—*Analysis of a normal water from Massachusetts.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Decided	6.0	1.252	0.000	0.000	0.000	1.1	51.5

Turbidity.—The term "turbidity," in the first column, defines itself, and in the analysis above set forth the degree of turbidity is expressed by the word "decided." The terms here used to express various degrees of turbidity, from lowest to highest, are as follows: "Very slight," "slight," "distinct," and "decided." This nomenclature is now used in only a few laboratories. In more recent analytical procedure turbidity is expressed according to a standard scale, the details of which are described in Circular No. 8 of the Division of Hydrography of the United States Geological Survey.

There are several highly important reasons for knowing turbidity, which make necessary the fine adjustment of an apparatus for its determination. Turbidity is a physical condition of water which must be measured by comparison with standards which are arbitrarily adopted. A clear water is most acceptable as a beverage. The most slovenly of mankind have an inherent dislike for a turbid draft, and even horses refuse to drink a water of doubtful appearance. Turbidity is the result of various causes, and a trained observer can infer a surprising number of facts concerning the history of a water and the condition of the area from which it comes by a superficial survey of the visible foreign matter held in suspension. A highly turbid water is unsuitable for many domestic and manufacturing purposes, and therefore the accurate determination of the degree of turbidity at the beginning of an investigation in some cases obviates the necessity of further work.

Odor.—The determination of the odor of waters is important, as from it we can sometimes determine the origin of the water or the pollution which it contains. Odors are often imparted to water by the green plants which grow in it, sometimes to a disagreeable extent. For a description of the method of describing odor, reference should be made to Circular 9 of the Division of Hydrography.

Color.—Returning to the analysis above set forth, the color denoted as 6.0 means *that, compared* with an arbitrary standard, prepared

and adopted as such, this sample bears the relation of 6 to 1,000,000; that is, a standard brown color having been determined upon, the sample under investigation is compared with known dilutions of the standard, and the dilution having the tint nearest to the sample is the one which designates the color of the water.

Nitrogen.—The next division of the analysis is entitled "nitrogen," and is subdivided into "albuminoid ammonia," "free ammonia," "nitrites," and "nitrates."

Albuminoid ammonia.—Albuminoid ammonia represents the nitrogen in the original combination referred to above; that is, before decomposition has set in. From the results of the determination of the amount of albuminoid ammonia in a sample of water we can infer with a fair degree of accuracy the amount of organic matter it contains. This does not, however, give any clue as to the character of the organic matter, whether animal or vegetable. We may find in a polluted water a smaller amount of this ingredient than may exist in a normal water perfectly acceptable for drinking purposes. In the analysis reported above is set down a comparatively large amount of albuminoid ammonia, 1.252 parts per million; this water, however, is unpolluted by dangerous wastes. On the other hand, in several waters the nature of which is known to be very dangerous, there were found only 0.284, 0.196, 0.198, 0.262, and 0.263 parts per million. The determination reveals, then, only the quantity of organic matter present, and in order to decide whether it is of a dangerous nature or not we must look further. If it is found that the organic material is principally vegetable matter, which is far less susceptible to decay than animal matter, the water which contains it may be fit for household purposes if the taste, color, odor, etc., are acceptable. This, however, can not be determined by analysis, but must be the result of inspection of the water course.

Free ammonia.—Free ammonia is the product of the first process of decay of organic matter. Its presence, as such, in a water is not more harmful than that of albuminoid ammonia. It denotes that decomposition is incomplete; that it has been arrested or retarded. It is not necessary, nor, indeed, natural, that any considerable inhibition of the process of decay should take place, and when such retardation occurs, as is shown by a high proportion of free ammonia, there must be some cause for it. We have said that a controlling factor in this process of oxidation is the presence of oxygen. Now, if a water contain a large amount of organic matter in a putrescible state, its breaking down into carbon dioxide and ammonia may go on so rapidly that it consumes all or nearly all of the available oxygen. This is certainly the case with sewage, in which there is a large amount of organic matter undergoing rapid decomposition. In the following reports of analyses this is well illustrated. The first is a repetition of what is found on page 23, while the second is that of a polluted water.

TABLE 2.—*Analyses of a normal and a polluted water from Massachusetts.*

[Parts per million.]

Character of water.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Normal....	Decided	6.0	1.252	0.000	0.000	0.000	1.1	51.5
Polluted..	Slight..	1.5	.263	.664	.025	.800	24.1	127.0

It will be seen upon examination of the above that in the polluted water the turbidity is less than in the normal water, the color considerably less, the total residue smaller in amount, and the albuminoid ammonia only 22 per cent of that in the normal water. When, however, we observe the comparative amounts of free ammonia, we find that in the unpolluted water there is none, while in the other there are 0.664 parts per million. This satisfactorily bears out the statements made in the preceding paragraph. It is evident that although the albuminoid ammonia in the polluted water has been so oxidized that the amount remaining can not be regarded as high, the free ammonia has not decreased in proportion. The cause of this must therefore be that the organic matter in the polluted water is so readily decomposed that it has consumed or was consuming all the available oxygen at the time the analysis was made. The fact that in the normal water there is reported no free ammonia indicates one of two conditions: (1) Either that algæ have consumed, as food, all the free ammonia as fast as it has been made, or (2) that the organic matter is not readily oxidized. We shall consider further on just which is the most likely deduction. High free ammonia may therefore be an indication of sewage pollution; at any rate it implies a rapid decomposition of organic matter.

Nitrites.—The presence of nitrites in a water is another indication of the incomplete oxidation of organic matter. It is only one step further in the process of oxidation, and as such, it must bear much the same significance as the presence of free ammonia. A nitrite is an even less stable condition of nitrogen than free ammonia; in fact, it represents nothing more than a short period of transition between free ammonia and the nitrates. Even in sewage-polluted waters it does not occur in so large a proportion as do the other forms of nitrogen. Rapid indeed must be the initial stage of oxidation of organic matter in order to allow the accumulation of nitrites. According to the analyses reported in Table 2 there are no nitrites contained in the normal water, but there are 0.025 parts per million in the polluted sample. The latter amount may be regarded as extremely high, and, taken with the high free ammonia, is almost certainly due to sewage pollution.

Nitrates.—The nitrates found in a water represent the complete mineralization of organic matter. When such matter, from whatever source derived, has reached this state it is entirely harmless. This is by no means equivalent to saying that a water with a high amount of nitrates and an insignificant quantity of the other forms of nitrogen is safe for drinking. There is no necessary connection between the amount of nitrates and the good or bad qualities of the water for public use. The question of the presence of the specific germs of disease is all-important and will be hereinafter considered. The presence of nitrates in a water, therefore, indicates nothing more than "previous sewage contamination." Of itself it is quite insignificant, but, taken into consideration with the determinations heretofore discussed, forms the final link in the chain which secures for us a knowledge of the history of a water under examination.

On referring again to the two analyses in Table 2 it will be noted that the amount of nitrates in the polluted water is large, indicating previous pollution. Yet it does not in any sense indicate that that pollution was dangerous. The report of analysis of the normal water shows that there are no nitrates. This is both uncommon and interesting. The amount of albuminoid ammonia in this sample is large, and under ordinary circumstances we might reasonably expect that there would appear at least a characteristic amount of the end product—nitrates. But as none appears we must conclude from the analysis that the organic matter in the water is of a kind that resists decomposition, and that as fast as the process is accomplished the algæ consume the ammonia, so that none appears in the various stages of oxidation.

Chlorine.—Little or no mention has been made of this substance in the previous pages in order that the discussion of the changes which take place in organic matter might not be complicated by other considerations. Few if any determinations in the whole range of water analysis are as important as that of chlorine. It bears absolute testimony concerning the history of the water, and its interpretation is dependent upon none of the other determinations. It may be under certain circumstances the crucial test by which a water may be accepted or rejected for potable use.

It is well known that chloride—that is, a chemical combination of chlorine with another element of a certain class, such as silver, magnesium, potassium, or sodium—are found in the earth in quantities varying according to the chemical nature of the geological formations. The most common of these is sodium chloride, familiarly known as common salt. These substances dissolve in water, some readily, others slowly, so that water that has passed through or over the ground is nearly always found to contain chlorides, generally common salt. Salt is found in the air, especially near the seacoast, and is one of the component parts of organic matter. The water

which flows over the surface of the land bears onward to the ocean an appreciable amount of salt in solution, a fact which is attested in a familiar manner by the saltness of the ocean and some of our great lakes which have no outlet. The wind blowing over the sea, driving it into spray, raises fine particles of salt, which are carried through the air over the land. These particles, being brought down by the rain, influence the amount of salt which is found in normal waters.

The work of the Massachusetts State Board of Health in the determination of the amount of common salt in normal waters has become classical. In a long series of analyses of normal waters selected in every part of the State it was found that there are distinct regions in which the amount of salt does not vary, except within very narrow limits, and that areas of equal normal chlorine may be defined upon a map of the State. It was found that the boundary lines of such districts follow roughly the coast line, and as the coast is receded from the amount of salt in normal waters grows less. This work has been taken up in Connecticut, Vermont, New Jersey, Ohio, and various other States. (See fig. 1.) How is such a map to be put to practical use? Before considering this question it will be necessary to take up the matter of significance of common salt in surface waters.

Common salt is composed of sodium and chlorine in equal proportions. Therefore, if it is desired to determine the amount of salt in a given water, it is only necessary to isolate one of these elements and the amount found will represent the whole. It is, for known chemical reasons, better to determine the chlorine, and therefore in an analysis of water like that in Table 1 the column "chlorine" represents the amount of chlorides, usually common salt.

We have said that salt is one of the component parts of both animal and vegetable matter. When a surface water is collected into a stream it contains chlorine that has been derived from vegetation as well as from the air and earth. Now, the amount of chlorine to be gathered from the vegetation of a district is as constant as that derived from the air or ground. When, however, animal matter is poured into the water there is an immediate rise in the amount of chlorine, which, obviously, can not be accounted for by any change in the natural conditions of the drainage area. It is clearly a contribution from sources other than those normally existing. The waste products of man, such as urine and faeces, and of the household, such as garbage and wash water, contain large amounts of salt, and when such waste is turned into a river its presence is easily detected. Now, the use of a normal chlorine map becomes apparent; whenever the water from any district is analyzed it is only necessary to compare the content of chlorine found with the normal content for that district, as shown on the map, and if the analysis shows a higher amount there is only one deduction to be made—that is, the water is or has been polluted with sewage.

When chlorine is once introduced into a water it remains throughout the journey to the sea, accumulating according normal content of the country or the pollution introduced. organic matter may be completely oxidized, generations of alg mature and die, color, hardness, turbidity, odor, and all els change, but chlorine remains fast. Public sewers may be intr into a river and change it to a stream of reeking filth; mile afterwards be traversed; sedimentation, oxidation, and the mo tle filtration may take place, and the water may again be s for drinking, yet the actual amount of chlorine carried along stream does not, under usual circumstances, decrease appre It may appear in smaller proportion at one point than at anoth

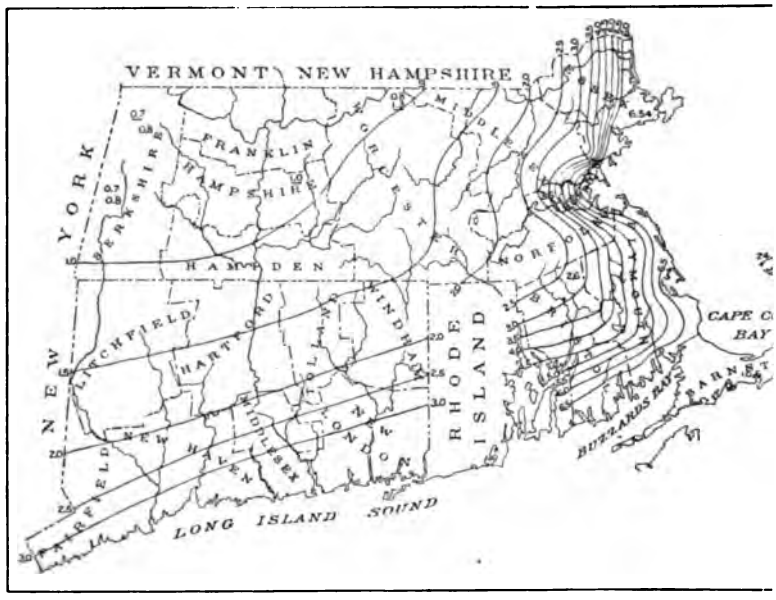


FIG. 1. Normal chlorine map of Massachusetts and Connecticut.

not by reason of any reduction of the actual amount of chlorin illustrate, the water of the Blackstone River just below the Wo precipitation works contained in the year 1900 an average parts of chlorine per million; after flowing a few miles to Ux it contained 13.8 parts, and finally at Millville, a short distance the State line, it contained only 9.3 parts. The river in its p from Worcester to Millville receives a comparatively large amo pure water from its tributaries, also a large amount of pollutio different establishments along its course, but the amount of added is in no way proportional to the amount of pure water c uted. Therefore the proportion of chlorine to water must grow along the course from Worcester to Millville. It is obvious th

proportion of chlorine is never reduced to an amount equal to the normal, and therefore must bear evidence of former abuse. The abnormal chlorine in a water may be likened to the scar left from some ugly wound; although the parts may be united and the surrounding tissues be healthy, yet the mark of former injury can never be effaced.

Total residue.—Under "Total residue" are included all matters, organic or mineral, which serve to pollute the water. In the above analysis it means that if 1,000,000 parts of water were evaporated there would remain in the container 51.5 parts of residue, which would represent practically the weight of the total impurity.

Analyses of normal and polluted waters.—The following analyses of normal and polluted waters, taken from the special report upon the "Examination of water supplies," made by the Massachusetts State Board of Health in 1890, are very useful in illustrating the principles above set forth. The first set of analyses represents normal waters and the second polluted waters.

TABLE 3.—*Analyses of normal and polluted waters.*

[Parts per million.]

NORMAL WATER.

No.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
1	None	0	0.022	0.000	0.000	0.060	0.8	50.0
2	Decided	1	.702	.000	.006	.030	1.0	25.0
3	....do	6	1.252	.000	.000	.000	1.1	51.5
4	Slight	4	.333	.130	.001	.250	1.6	36.5
5	....do	3	.136	.000	.000	.050	6.3	32.5
6	....do	0	.152	.000	.000	.060	21.0	59.5

POLLUTED WATER.

7	Distinct	1	0.284	0.124	0.009	0.150	1.9	107.5
8	Very slight	5.5	.196	.000	.004	.550	5.4	51.5
9	Distinct	1.0	.198	.016	.004	.200	5.8	50.0
10	Slight	1.5	.262	.000	.010	.170	20.9	102.5
11	....do	1.5	.263	.664	.025	.800	24.1	127.0

Careful examination of the above table shows that chemical analyses alone may furnish very little information concerning the healthfulness of a water unless certain matters determined are in exceedingly high

proportion. Analysis 11, in Table 3, for instance, is such that a person could, with a fair degree of safety, condemn the water. The free ammonia, nitrites, and chlorine are high, giving evidence which is unmistakable. Sewage is poured into the body of water from which this sample is taken.

Supposing, however, this series of analyses was not divided into "normal" and "polluted," how would we be able to place 8 in its proper position under "polluted waters?" The results of the determinations in this analysis appear lower than some of those in the normal list. On comparing it with 4, for instance, it will be seen that in the polluted water the turbidity is less, the color not much more, the total amount of organic matter not greatly different. The free and albuminoid ammonia are much less in the polluted water; the nitrites are considerably more, but not so great as in normal water 2. The nitrates are higher, but this, as has been explained, means little so far as the healthfulness of the water is concerned. The marked difference in the two seems to be in the amount of chlorine, but if we glance at the normal chlorine map (fig. 1) it will be seen that if 8 were collected in the region of Boston and 4 were collected farther west, these amounts of chlorine would both be normal. If we do not know where they were collected or whether the nitrogen compounds are the result of decomposition of harmless vegetable matter or dangerous animal waste, the bare water analyses are nearly worthless; but taken in connection with a knowledge of the locality, population, and sewerage conditions within the drainage area, the analyses are preeminently useful in determining the conditions of the water.

Hardness.—Some of the damages done by the use of hard water have already been referred to under the title "Use in boilers" (p. 14). In a public supply a hard water is troublesome and expensive by reason of the fact that when it is used for household washing it requires a larger amount of soap to produce the desired result. The fatty acids in the soap must first neutralize the calcareous matter in the water before it can be used for washing. A uniform scale for the determination of hardness is at present the subject of considerable thought among water analysts. The present methods, however, are efficient to a certain degree of accuracy and enable us to distinguish a soft water from a hard one.

There are two grades or kinds of hardness which will, wherever possible, be distinguished in the following pages. The first is due to the presence of alkaline carbonates, such as calcium, sodium, and magnesium carbonates. When water containing these compounds is boiled their effect quickly passes off; consequently it is designated as "temporary hardness," or, as it will be termed in this review, "alkalinity." The second grade of hardness is due to the presence of alkaline sulphates, chlorides, and nitrates. They do not disappear upon

boiling, and therefore maintain a "permanent hardness" or "normal hardness."

In the succeeding pages, in the case of New England, where the total hardness—that is, both temporary and permanent together—has been determined, the amounts indicating the degree of hardness are the result of a reduction of the amounts of all alkaline earth salts to terms of an equivalent amount of carbonate of lime. In other words, in Table 7 the statement of the hardness as 11 means that the water contains an amount of alkaline salts which make it as hard as would have been produced by 11 parts of carbonate of lime per million. In the statement of the hardness in the case of waters in the Ohio Basin, on the other hand, where the hardness is divided into "temporary" and "permanent," the temporary hardness indicates the amount of alkaline carbonates reduced to an equivalent of calcium carbonate; and in the case of permanent hardness, the amounts include the alkaline sulphates, chlorides, and nitrates reduced to an equivalent of calcium carbonate.

Summary.—In the preceding pages an attempt has been made to briefly and plainly state the characteristics demanded of a water required for public and household uses. Many details have been purposely omitted, but it is believed that enough has been said to enable the reader to comprehend the changes that take place in the dangerous or undesirable ingredients common to water supplies, a knowledge of which is necessary to a proper understanding of the contents of the following pages.

POLLUTION OF NATURAL WATERS.

The pollution of natural waters, though it may be sometimes unavoidable, is usually highly damaging to the resources of the country in which it takes place. The matter is a troublesome one in populous countries and has occupied the attention of chemists, engineers, land promoters, and others, as well as of courts of law, having been a fruitful source of litigation. The basis of action in all cases of this character is founded on the principles of common law in respect of the ownership of real property. The title of a land owner presumptively extends upward to the clouds and downward to the earth's center, embracing everything upon the surface and beneath it. This includes the mineral wealth in the ground and arising out of it, such as coal, iron, copper, oil, water, and even gas. The water flowing from a spring situated upon a certain piece of property belongs to the owner of the land as truly as do the blades of grass that grow upon it. A water right, whether it be vested in a spring, well, or river, is appurtenant to the land and passes with it by conveyance. The ownership so secured carries with it the assurance that all water passing out of or over the property shall be normal, and that any pollution

other than that caused by the natural drainage of occupied land lyi above is actionable in law.

The situation is well summed up in a few paragraphs from t American and English Encyclopedia of Law, volume 28, under t heading "Water courses:"

Riparian rights are the correlative rights of adjoining proprietors upon t banks of water courses with respect to the water thereof. * * * The prope in the water is indivisible, and all proprietors are entitled to an equality of rig therein.

In consequence of the common right of riparian proprietors to the benefits water flowing through their land the general rule is that no proprietor has t right to use the water to the prejudice of another. This principle, however, d not restrain the use of the waters, so that there can be no diminution or impe ment whatever, but the true measure and standard of the use which a ripari owner may make of his right is the reasonableness thereof. Each is entitled a reasonable use for domestic, agricultural, and manufacturing purposes, * * reasonable with respect to the rights of others.

A right to a reasonable use includes the right to release, let down, and d charge waters in order beneficially to employ them; and the exercise of the rig entails no liability for injuries necessarily caused thereby to others in regard the rise of the stream; yet if the discharge withdraws from another the use of t waters to which he is entitled, or if it needlessly deprives another of his benefic use, or injures or destroys another's property, a case for damages is presented.

The right to the reasonable use of the water of a stream not navigable th flows through ones land includes the right to confine and obstruct its flow wi dams in order to utilize the water power, or, for other beneficial purposes, detain the water for such a length of time as it may be reasonably necessary f such use, notwithstanding the detention injuriously interferes with another's ex cise of his right to the reasonable use of the stream in its natural state.

The right of every owner of land through which a stream of water flows have the same flow in its natural state extends to the quality as well as the qua tity of water, and therefore one who pollutes or contaminates water may be lia to those injured thereby, and a court of equity will interfere by injunction restrain such use as will cause an irreparable damage or endanger the compla ant's rights by adverse possession if continued.

A frequent ground of action arises from the operation of mills and factories, t refuse from which poisons, corrupts, and renders unwholesome the waters of stream, or in some other way impairs it usefulness. The deposit of dyestu whereby a stream is polluted or discolored; the discharge of poisonous or cor sive substances into a stream, whereby the machinery of lower riparian own has been injured; emptying offensive matters from tanyards, and deposits of sa dust waste or refuse of mills to the injury of lower proprietors, have been held be actionable and proper grounds for injunction.

A riparian proprietor who pollutes a stream by an unreasonable discharge sewage, to the injury and inconvenience of lower riparian owners, is liable f damages therefor. If a muncipal corporation causes sewage to pollute a wa course, to the use of which a lower landowner through whose premises passes is entitled, it is guilty of a nuisance, for which damages may be recover

It appears, then, that there is no legal justification for the pollut of water, yet so universal is the practice that it has come to recei moral justification at the hands of society and meets no general co

demnation except in cases where it goes beyond the bounds of human endurance. A few States in the Union have recognized the damage arising from water pollution and have made intelligent investigations for the purpose of correcting the evil. The results of some of these investigations will be presented in the following pages, together with the results of examinations made by several towns and cities as a consequence of local necessities. The data are arranged according to drainage areas, and in the case of interstate rivers, where the work has occurred in several States, the results obtained for a particular stream will be combined.

MERRIMAC RIVER BASIN.

GENERAL FEATURES AND METHODS OF UTILIZATION.

Course and drainage area.—The Merrimac drainage basin is 4,553 square miles in extent. (See fig. 2.) It is situated in New Hampshire and Massachusetts, occupying in the latter State 1,136 square miles. The Merrimac River proper is formed by the junction of the Winnepesaukee and Pemigewasset rivers at Franklin, N. H., from which place to its mouth, at Newburyport, Mass., it is about 110 miles long. From Franklin it takes a south-southeasterly course until it passes for a short distance into Massachusetts, when it abruptly turns northeastward and enters the Atlantic Ocean.

There is a wide variation in the physical characters of the Merrimac Basin. A large part of it is highly cultivated and fertile, but at the headwaters of the different tributaries the country is exceedingly rough and rugged. A small part of the area is low and swampy. Forests worthy of the name are almost entirely wanting in large parts of the basin, their absence causing a certain inconstancy in the flow of the river, but this has been in a measure corrected by a thorough system of storage, natural and artificial.

Throughout the basin the underlying rock is largely granite, which furnishes a valuable source of supply for building materials.

Storage.—Within the drainage area of the Merrimac are many lakes, ponds, and artificial reservoirs which afford excellent storage, and, as has been stated, compensate in a measure for the effects of extensive deforestation. The most important of these are Lake Winnepesaukee and Long Bay, covering 71.75 square miles; Squam, New Found, Belmont, and Massabesic lakes, Smiths and Suncook ponds, and a long chain of reservoirs in Massachusetts, which conserve a water supply for the "Metropolitan district."

Transportation.—The river is not important as a means of transportation. Small coastwise vessels may ascend as far as Haverhill only, and the amount of traffic is not large.

Power.—As a source of water power the Merrimac throughout its

whole extent is justly famous. In the main river there is a total fall of 269 feet in 110 miles, an average of 2.45 feet per mile. This fall however, is concentrated at six principal points, giving most advan

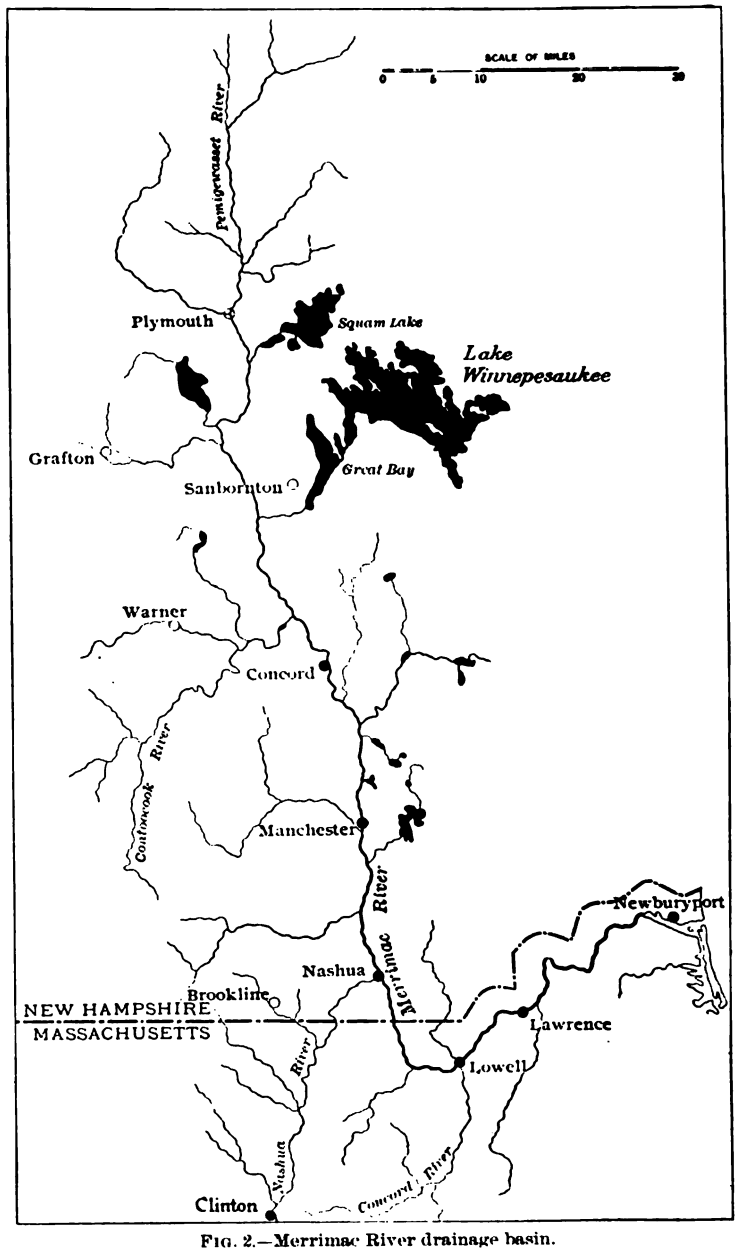


FIG. 2.—Merrimac River drainage basin.

tageous power facilities. Up to the present time there have b *utilized over* 40,000 horsepower at Lowell, Lawrence, and Manches

On the tributaries, too, there are a large number of power sites, which have been utilized extensively. In Table 4 is given the total utilized horsepower on each important tributary. Some of these, especially in the drainage area of the Concord and Nashua rivers, have been abandoned to make way for the metropolitan water-supply system.

TABLE 4.—*Utilized horsepower of tributaries of Merrimac River.*

Branch.	Total utilized horsepower.	Drainage area (square miles).
Powwow River	1,850	50
Shawsheen River	645	72
Spickett River	701	79
Beaver Brook	687	92
Concord River	4,962	380
Stony Brook	904	35
Nashua River	11,762	516
Souhegan River	2,451	224
Cohas Brook	170	44
Piscataquog River	1,250	214
Suncook River	2,881	264
Soucook River	72	90
Contoocook River	6,360	766
Winnepesaukee River	6,503	480
Pemigewasset River	4,114	1,013
Total	45,312	.....

Ice.—With the exception of Lake Winnepesaukeé there are no very large ice fields within the Merrimac drainage area. Taken collectively, however, the ice industry is very large, each pond or lake which has remained sufficiently pure being the source of supply for the country immediately surrounding. There are no reliable records of the size of the ice crop within this basin. The industry is largely localized, each field having a different ownership, and the returns made by the different owners are certainly not correct, for the endeavor to escape taxation has induced the several companies to make returns which are usually far below the actual amount of ice cut. The common measurement of ice in the fields is 1,000 tons to the acre, the ice being about 12 inches thick. Within the Merrimac Basin it is possible to cut two or three crops. According to the Tenth Census report on water power there are about 100 square miles of pondage in this basin, equal to 64,000 acres. Assuming that 25 per cent of this area is available for ice cutting and allowing for only one crop during the season, which is certainly a low average, there would be available

160,000 tons on the lakes alone. Allowing for a large crop on the rivers, it appears that 1,000,000 tons a season is a conservative estimate, and the total amount cut is probably far more than this. At all events, the value of this system as a source of ice supply is very great.

FLOW MEASUREMENTS.

During a series of years the flow of the Merrimac has been carefully measured at Lawrence, and the discharge is given in the following table:

TABLE 5.—*Estimated annual discharge of Merrimac River at Lawrence, Mass.*

[Drainage area, 4,553 square miles.]

Year.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Depth in inches.	Second-feet per square mile.
1890	31,560	590	9,373	6,785,786	27.93	2.06
1891	39,000	280	8,370	6,033,916	24.84	1.48
1892	24,800	225	5,869	4,264,911	17.58	1.29
1893	44,800	286	4,850	4,726,807	19.47	1.43
1894	27,900	104	5,035	3,645,052	15.03	1.11
1895	65,300	71	5,799	4,196,973	17.25	1.27
1896	82,150	183	7,187	5,203,029	21.40	1.58
1897	41,499	176	8,002	5,800,105	23.90	1.76
1898	36,000	372	8,413	5,092,341	25.05	1.85
1899	38,200	50	6,464	4,672,824	1.42	19.20

On the Sudbury River, tributary to the Concord, measurements of flow have been regularly made since the year 1875, and are set forth in the following table:

TABLE 6.—*Mean flow of Sudbury River in cubic feet per second, 1875–1900.*

[Drainage area, 75.2 square miles.]

Year.	Second-feet	Year.	Second-feet.	Year.	Second-feet.
1875	111	1885	105	1895	134
1876	118	1886	126	1896	119
1877	141	1887	134	1897	114
1878	169	1888	197	1898	153
1879	104	1889	176	1899	113
1880	67	1890	149	1900	126
1881	114	1891	150	Mean	124
1882	100	1892	90		
1883	62	1893	120		
1884	131	1894	89		

CHARACTER OF NORMAL WATER IN THE MERRIMAC BASIN.

The waters of the Merrimac have been studied more carefully, probably, than those of any other river in the world. The Massachusetts State Board of Health, famous for its pioneer work in modern river survey, has determined very closely the character of the water in that part of the drainage area that lies within the State. No work of importance has been done by the State of New Hampshire, but the waters of the Winnepesaukee have been carefully analyzed by the Commonwealth of Massachusetts. The natural conditions in the drainage area are, however, sufficiently uniform to warrant the assumption that the normal characteristics of the headwaters in Massachusetts are representative for the whole area.

Tables 7 and 8, the first consisting of analyses of practically normal surface waters and the second consisting of analyses of normal ground waters, will fairly serve as an index of the character of unpolluted water in the Merrimac Basin. The last column in these tables shows the number of analyses on which the averages stated were based.

TABLE 7.—*Analyses of normal surface waters in Merrimac Basin.*

[Parts per million.]

Place of collection.	Turbidity.	Color.[a]	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Sudbury reservoir		2.2	0.175	0.030	0.001	0.054	2.2	36.2	11	52
Framingham reservoir.	Slight to decided	1.9	.170	.022	.001	.037	2.3	36.3	12	12
Ashland reservoir	do	6.8	.223	.012	.001	.047	2.4	37.2		(b)
Nagog Pond, Acton	None to slight	.5	.170	.005	.000	.011	2.4	20.9	2	11
Scott reservoir, Fitchburg.	Slight to decided	1.6	.227	.008	.001	.020	1.4	26.1	2	4
Haynes reservoir, Leominster.	do	1.6	.304	.016	.000	.020	1.0	18.7	1	4
Morse reservoir, Leominster.	Very slight to slight.	2.3	.198	.007	.000	.030	1.2	21.0	2	4
Sandy Pond, Concord.		.3	.129	.001	.001	.041	2.5	26.6	.....	.....
Crystal Lake, Haverhill.		1.3	.106	.009	.....	.030	3.0	32.2	.....	.....
Lake Winnepesaukee.		1.0	.063	.002	.000	.038	[c]1.2	30.9	.....	24
Penacook Lake, New Hampshire.[d]		1.0	.138	.020	.000	.000	1.4	32.0	11	1

[a] Nessler scale.
[b] Over 80, extending over 13 years.
[c] Excess of chlorine, 0.2.
[d] Furnished by H. E. Barnard, New Hampshire State Laboratory of Hygiene.

TABLE 8.—*Analyses of normal ground waters in Merrimac Basin.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analysis.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
El-Hazar, Lowell	2	0.012	0.004	0.000	0.025	1.0	24.0	5	
Ballardvale, Andover	3	.012	.003	.000	.035	2.4	23.5	4	
Framingham	1	.025	.000	.000	.095	2.2	38.0	17	
Peppereil	1	.006	.003	.000	.085	1.5	53.0	24.5	
Concord	0	.025	.008	.000	.200	2.6	26.5	4	
Methuen	0	.012	.003	.000	.150	2.0	85.0	21	
Chelmsford	2	.022	.006	.000	.510	2.8	27.0	6	
Dracut	2	.077	.008	.000	.040	2.7	33.5	6.5	
Well in Sandbarton	0	.000	.000	.000	.300	1.76	55.0	2.0	

POLLUTION IN THE MERRIMAC BASIN.

The country drained by the Merrimac River system contains a po ulation of about 632,560, according to the national census of 190 Of this number, 414,040 dwell in Massachusetts. The population p square mile within the whole area is therefore 151; that in Ne Hampshire is 71.4; that in Massachusetts is 364.4. A large proporti of this population is concentrated within cities and large towns, that the above figures do not, even approximately, represent t actual conditions in the drainage area.

Pollution exists in the basin to an extent that has made the wat a fruitful source of study. On the main river, between Newburypo Mass., and Concord, N. H., there is a large civic population suppli with sewerage systems, from which large volumes of crude sewa are daily poured. Some of the tributaries also receive a damagi amount of pollution. The latter will first receive attention, and th effects will be gathered together and summed up in connection wi the pollution in the Merrimac proper.

SHAWSHEEN RIVER.

Rising in the historic town of Lexington, Mass., the Shawshe runs in a northerly direction and enters the Merrimac at Lawren It is a somewhat unimportant stream from the standpoint of natu resource; the flow is unsteady and the power values poor. As source of water supply it would furnish in the driest year abo 20,000,000 gallons of bad water daily from the 34.1 square miles *the upper end of* the drainage basin.

The population of the portion of the area above mentioned is abo *125 per square* mile, and appears to be growing rapidly. Few pre

tions have been taken to keep the waste from this number of people out of the river, and the country is highly fertile and swampy to a large degree, so that the water of the river contains an abundance of organic matter and has a high color.

Analyses of the water of the river have been made by the State Board of Health, as follows:

TABLE 9.—*Analyses of water from Shawsheen River.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as -				Chlorine.	Total residue.	Hardness.	Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Bedford	Slight	15	0.311	0.080	0.002	0.065	5.9	76.7	32	2
Wilmington	None to distinct.	9.6	.272	.018	.001	.085	3.5	56.3	.....	24
Andover	Slight to decided	5.1	.385	.074	.001	.047	4.2	55.7	13	3
North Andover	Slight	8.5	.306	.106	.005	.250	3.6	53.5	13	1

The special report of the State Board of Health of Massachusetts, made in 1895, upon the metropolitan water supply has the following:

It was the general opinion from 1874 to 1887 that the water of the Shawsheen River was of satisfactory quality for the purposes of a public water supply; but the investigations of the State board of health since the latter year have shown that this is not the case. The population upon the watershed (123 per square mile) is not very large, but the headwaters of the stream are in the town of Lexington, within 10 miles of the statehouse, where there is likely to be a large growth in the future, and the territory in and beyond Lexington is used to an increasing extent for market gardening. The watershed also contains many swamps, from which the water acquires a high color and takes up much nitrogenous organic matter.[a]

CONCORD RIVER.

Sudbury and Assabet rivers join at Concord, Mass., to form the Concord, which from this point flows in a northerly direction to join the Merrimac at Lowell. (See fig. 3.) The country drained by the system varies in character, a part being extremely flat meadow land, through which the river winds sluggishly, while the remainder is of the hilly, rolling character common to Massachusetts. The Assabet Basin and the upper part of the Sudbury are of the latter character, but the Lower Sudbury and the Concord, from the town of Concord to Billerica, are very flat. Two miles from its junction with the Merrimac there is a fall of 40 feet in the Concord, corresponding to the fall in the Merrimac at Lowell.

[a] *Report Massachusetts State Board of Health upon a Metropolitan Water Supply*, p. 114.

Pollution in the Concord system has been accurately determined. The Upper Sudbury is set apart as a drainage area for a part of the supply of the Massachusetts metropolitan district, and for years

FIG. 3.—Concord River drainage basin.

accurate analyses have been made. The Assabet has been examined with reference to its use as a future source of supply, and the Concord has received attention all along its course.

SUDBURY RIVER.

Drainage area.—In the Sudbury area the city of Boston had six reservoirs built or started, utilizing the water from Farm Pond and Lake Cochituate, when the control was put into the hands of the Metropolitan Water Board. The drainage area here included is as follows:

	Sq. miles.
Reservoirs 1 to 6	74.656
Farm Pond	.543
Lake Cochituate	18.87
Total	94.069

Within this area are Marlboro, Southboro, Westboro, Hopkinton, *Ashland, and the* largest populated portions of Natick, Framingham,

Sherborn, and Wayland, all representing a population of about 45,300, or 482 per square mile.

Conditions in the area.—That waters can be conserved in so populous an area and delivered in good condition to the citizens of Boston without any purification save that occasioned by storage may be considered remarkable. It is commonly found that a river running out of a valley having so many persons per square mile as live in the basin of the Sudbury is so polluted that its use in the raw state is dangerous. The examination of the condition of the Shawsheen showed what may be expected even in a country with a population of 125 per square mile. It will therefore be profitable to consider the conditions

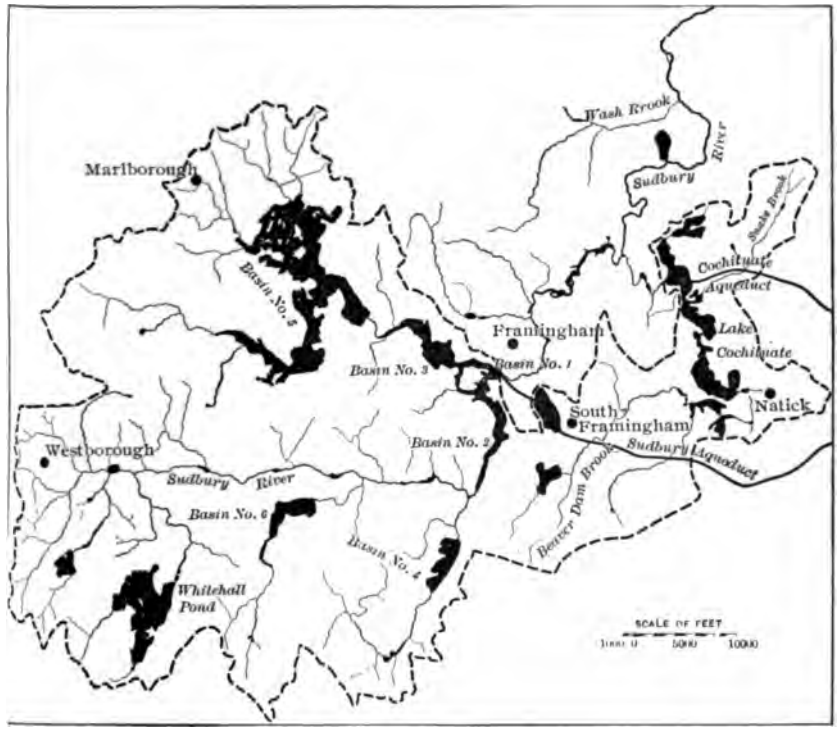


FIG. 4. Sudbury River drainage basin.

ithin the Sudbury area and show how it is possible to maintain the n-off water in a normal state.

Examination of the accompanying map of the area (see fig. 4) will ow that Westboro is situated on the western divide of the Sudbury, nd just beyond the divide is the sewage-disposal work for the town. n the northern boundary is Marlboro, a city of importance, and to ie east, over the divide, is another disposal works. In the stream nown as Walker Brook, running through Marlboro to the great Sudury reservoir, has been placed a filter, and all of the water from the

city of Marlboro, which, as shown by analysis, is extensively polluted, is purified before being mingled with the pure water in the reservoir. Within the Cochituate Basin are South Framingham and Natick, both with sewerage systems and sewage-disposal works the latter situated outside of the drainage area. In addition to this, a filtration system has been established at the Reformatory Prison for Women, while the water of Pegan Brook, running from Natick into Lake Cochituate, is filtered like that of Walker Brook in Marlboro. The differences between the waters of this area and those of others having an equal population are due entirely to these precautions.

Out of the Sudbury and Cochituate basins there were daily drawn in the year 1902 about 41 million gallons of water. If it were not for the filtration of polluted water described in the foregoing paragraph, the water from this area would be quite unfit for domestic use, and this large investment would diminish in value or would fail completely. It would be necessary to filter the entire output, which would cost at least $5 per 1,000,000 gallons, or, at the present rate of consumption, $74,800 annually. Under the present conditions the expense of sewage purification in the Sudbury and Cochituate basins amounts to a small fraction of this sum annually. Thus by an expenditure of a small amount of money for the construction of disposal works and a comparatively insignificant amount for maintenance the value of the Sudbury resource is preserved. This is a typical case, illustrating what may be done in the way of preserving in its normal state the water of a populous district. It stands forth in contrast to the many cases hereinafter taken up, in which all thought of preservation of values undamaged is thrown to the winds.

Character of water.—The character of the water in the Upper Sudbury Basin is well set forth in the first three analyses in Table 7, page 37. It will be seen that from all evidences the precautions taken are successful, for the waters are practically normal. The Cochituate water is also nearly normal and is similar in many respects to that of the Sudbury, possessing, however, a much lighter color. The color of the Sudbury water has been improved during recent years by the drainage of swamp lands in the watershed.

Passing out of the hilly region, the Sudbury winds along the plain through the towns of Sudbury, Wayland, and Lincoln, carrying along the incidental pollution from these places as well as that from Framingham Center and the effluent from the Natick, Marlboro, and Framingham filter beds. This pollution has its effect upon the river, as is shown by the marked change in the character of the water. The following analyses of waters, taken along the Sudbury, Assabet, and Concord at different points, are reproduced from the report of the Massachusetts State Board of Health for 1900.

TABLE 10.—*Analyses of water from Sudbury River between Saxonville and Wayland (Farm Bridge).*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	No.	Place of collection.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.					
Aug. 15, 1900	Very slight.	3.4	0.216	0.040	0.002	0.000	3.6	40.0	16	1	Dam above Saxonville Mills.
Aug. 29, 1900	....do....	2.2	.244	.012	.000	.080	3.6	40.0	16	2	Do.
Do.	Decided....	8.0	1.500	.390	.000	.020	9.0	118.0	22	3	3,000 feet below Saxonville dam.
Feb. 27, 1901	....do....	.....	2.720	5.040	.013	.200	11.1	162.5	27	4	4,000 feet below Saxonville dam.
Aug. 15, 1900	....do....	6.1	1.000	.110	.007	.010	7.3	90.5	20	5	1 mile below Saxonville dam.
Do.	....do....	6.1	.850	.140	.004	.010	6.9	108.0	22	6	2.7 miles below dam.
Aug. 29, 1900	....do....	3.3	.600	.300	.004	.070	8.7	92.5	26	7	Do.
Feb. 27, 1901	....do....	6.0	.940	.940	.070	1.020	16.8	153.0	39	8	Do.
Aug. 29, 1900	Slight....	3.0	.336	.136	.000	.020	8.0	69.5	26	9	4.1 miles below dam.
Aug. 15, 1900	....do....	3.0	.292	.136	.004	.010	6.3	74.5	25	10	6 miles below dam.
Aug. 29, 1900	....do....	2.9	.376	.032	.003	.010	8.3	80.0	26	11	Do.
Feb. 27, 1901	....do....	2.7	.208	.172	.018	.420	6.8	71.5	25	12	Do.

TABLE 11.—*Analyses of water from Sudbury River between Wayland and Concord.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	No.	Place of collection.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.					
Aug. 11, 1900	Slight....	2.9	0.246	0.072	0.005	0.030	6.6	61.5	22	13	Canal bridge.
Aug. 29, 1900	Very slight.	3.6	.258	.046	.002	.020	6.3	62.5	23	14	Do.
Feb. 27, 1901	....do....	2.9	.214	.244	.010	.410	6.5	64.5	22	15	Do.
Average.		3.1	.239	.121	.006	.153	6.5	62.8	22		
Aug. 15, 1900	Very slight.	3.0	.200	.022	.004	.000	5.6	56.0	23	16	Lee's bridge.
Aug. 29, 1900	....do....	2.3	.244	.030	.000	.020	6.8	58.0	20	17	Do.
Average.		2.6	.252	.026	.002	.010	6.2	57.0	21		
Aug. 15, 1900	Very slight.	3.0	.226	.026	.001	.000	6.0	54.0	20	18	Heath's bridge.
Aug. 29, 1900	....do....	1.9	.222	.024	.000	.030	5.8	58.5	18	19	Do.
Feb. 27, 1901	Slight....	3.6	.250	.142	.006	.380	6.2	71.5	20	20	Do.
Average.		2.8	.233	.064	.002	.137	6.0	61.3	19		
Aug. 15, 1900	Very slight.	3.0	.202	.044	.002	.000	5.8	55.0	22	21	Near mouth Concord.
Aug. 29, 1900	....do....	2.2	.222	.034	.000	.010	5.5	59.0	21	22	Do.
Feb. 28, 1901	Slight....	3.2	.274	.122	.005	.290	6.0	64.5	21	23	Do.
Feb. 27, 1901	....do....	3.7	.284	.144	.005	.380	5.9	65.0	21	24	Do.
Average.		3.0	.260	.086	.003	.170	5.8	60.9	21		

Findings.—The dates of collection of the samples reported in Tables 10 and 11 are well selected to show the character of the water in Sudbury River in midsummer and midwinter seasons. The analyses given show clearly the effects of pollution on the river along the entire course, from the borders of the restricted area to the mouth of the Assabet, in Concord. Samples 1 and 2, taken from the dam above Saxonville mills, show the effects of contamination from Framingham Center in the content of chlorine. The normal chlorine map shows that the proper amount for this area is about 2.5 parts per million, while that in the samples indicated is 3.6. The amount of nitrogen in the two determinations is noticeably low. This may be due in part to the short term of storage afforded in the mill pond above Saxonville dam, but the more correct explanation is probably that the water which runs out of the restricted area below the reservoirs has little polluting material turned into it, except that of an indirect nature, and the only testimony which remains is the abnormal amount of chlorine. As far as the analyses show, the water from above Saxonville dam may be taken to represent roughly the character of the unpolluted Sudbury water. A comparison with the analyses of the water taken from points below may be fairly made upon this basis. Nos. 3 and 4 show clearly the effects of pollution from Saxonville, while 5, 6, 7, and 8 well represent the effects of oxidation, sedimentation, and dilution with fairly pure water from small tributaries. No. 8 shows in an instructive way the difference in the purifying action of those three agents during the cold season. Nos. 9–12 in Table 10 and 13–24 in Table 11 present no remarkable features, and merely indicate the continued effects of self-purification in a river which runs through a district sparsely populated. It is interesting to note that the amount of chlorine remains high, increasing as the points of pollution are passed, and thereafter being reduced in proportion to the dilution from tributary streams.

ASSABET RIVER.

The drainage area of this river is a narrow one, lying between the drainage basin of the Sudbury and that of the Nashua. The country is fertile and the affluent from sewage-disposal works at Westboro and the pollution at the village of Northboro all assist in contaminating the stream. The special report of the State Board of Health in 1895, in considering future sources of supply for the metropolitan district, contains the following statement:

> Owing to the polluting matters which enter the streams at Northboro, to the very large area of swampy land along the river between Northboro and the Boston and Albany Railroad, and to the disposal of the sewage of Westboro upon the banks of this section of the river (Assabet), it is not of suitable quality for water supply purposes.

The analyses published at that time fully bore out this statement,

but since then the river has become more polluted. The annual report of the State board for the year 1900 contains the following analyses:

TABLE 12.—*Analyses of water from Assabet River.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as				Chlorine	Total residue.	Hardness.	Place of collection.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Feb. 27, 1901	Decided	5.0	0.520	0.204	0.002	0.280	4.3	69.0	16	2 miles above Northboro.
Aug. 15, 1900	Slight	5.4	.302	.100	.003	.000	5.2	53.0	18	Below Hudson.
Aug. 29, 1900	Decided	7.0	.110	.640	.001	.020	24.9	124.5	23	Do.
Feb. 27, 1901	do	3.3	.416	.256	.005	.300	15.9	80.5	18	Do.
Do	do	4.0	.336	.188	.005	.230	7.1	66.0	14	Below Gleasondale.
Aug. 15, 1900	do	3.0	.376	.140	.002	.000	6.7	53.5	11	Below Maynard.
Aug. 29, 1900	do	3.4	.425	.080	.003	.010	7.6	61.5	11	Do.
Feb. 27, 1901	do	3.5	.480	.288	.004	.200	7.1	70.5	16	Do.
Aug. 15, 1900	Slight	3.2	.388	.216	.007	.070	6.5	50.5	13	Near mouth.
Aug. 29, 1900	Very slight	2.4	.278	.138	.005	.040	7.8	57.5	13	Do.
Feb. 28, 1901	Slight	3.5	.308	.164	.004	.200	6.6	57.0	18	Do.
Feb. 27, 1901	do	3.5	.296	.220	.005	.280	5.9	63.0	16	Do.

CONCORD RIVER, BETWEEN CONCORD AND LOWELL.

Below Concord, the river slowly winds through a country of scanty population, without materially adding to the pollution which it bears along. The water perceptibly improves through the same agencies as are above noted in the case of the Sudbury, until it comes within the polluting influence of Lowell.

TABLE 13.—*Analyses of water taken at different points along Concord River.*

[Parts per million.]

Turbidity.	Color.	Ammonia.		Nitrogen as		Chlorine.	Total residue.	Hardness.	Place of collection.
		Albuminoid.	Free.	Nitrites.	Nitrates.				
Very slight	3.2	0.286	0.102	0.004	0.030	6.4	53.5	16	Below North Bridge, in Concord.
Do	3.0	.250	.080	.003	.040	6.7	55.0	17	At Flint's bridge, in Concord.
Slight	3.4	.278	.158	.005	.350	6.3	63.5	17	Junction Sudbury and Assabet.
Very slight	11.0	.352	.030	.002	.130	5.2	59.0	16	Billerica.
Do	2.6	.224	.044	.001	.010	9.4	61.0	25	Above Billerica waterworks.
Do	2.0	.222	.040	.000	.010	5.9	54.0	14	North Billerica.
Do	2.0	.220	.018	.000	.010	5.9	52.0	14	Above Talbot's mill, Billerica.

NASHUA RIVER.

Nashua River rises in Worcester County, Mass., and flows in a northeasterly direction into New Hampshire, where it joins the Merrimac at Nashua. Above Lancaster, Mass., the river divides into the North and South branches, the former coming down from the northwest, the latter having traced a circuitous course in a general northeasterly direction. (See fig. 5.)

FIG. 5.—Nashua River drainage basin.

There are situated within the Nashua Basin 23 municipalities, exclusive of Nashua, at the mouth, some of which extend over across the divide into other watersheds. The total population, according to the Twelfth Census, is about 83,200, or neary 161 per square mile. This, however, does not fairly represent the conditions upon the river system, for upon many branches the country is sparsely settled. Large settlements are not numerous, and only three are of important size. Fitchburg, on the North Branch, has a population of 31,531; Leominster, a short distance below, is reported to have 12,393; and Clinton, *the only important* center on the South Branch, has 10,251 inhabitants

SOUTH BRANCH OF NASHUA RIVER.

he South Branch of the Nashua has a drainage area of 129 square
s, the topography being hilly and steep, affording admirable
ortunities for storage. The upland branches, Quinepoxet and
water, join to form the South Branch, bringing in the waters of a
ıtry of small population and affording a supply of excellent qual-
Practically all of this upland area has been set aside by the
ropolitan Water Board for the conservation of a supply for Boston
vicinity. The river is intercepted by a mammoth dam, which
hold back the waters of one of the largest reservoirs ever con-
cted, at a point just above Clinton.
ıe waters of the reservoir will cover the present villages of
leston, West Boylston, and Harrisville, and the work of effacing
e places has already been carried forward. At the time of the first
rt on the project, in the year 1895, the population of the proposed
icted area of 118.23 miles was 61 per square mile. Since that
there has been practically no increase over the whole country,
recently the destruction of the villages above mentioned has
ed a marked decrease. The completion of this work will effect
ange in the quality of the water taken from this basin. The
points of pollution now existing there will be removed and stor-
in the new reservoir will improve the character of the water.
even now the supply which is taken from the river and carried
ugh the aqueduct constructed across the eastern watershed to the
bury Basin is of excellent quality and will serve as a normal from
h to consider the pollution in the lower reaches of the river.
erence to the map of normal chlorine, page 28, will show that the
ortion for this country is 1.6 parts per million.

uinepoxet and Stillwater rivers.—From the Massachusetts reports
been taken the following statements of analyses of waters gath-
from the Quinepoxet and Stillwater rivers, the one at Holden and
other at Sterling:

TABLE 14.—*Analyses of water from Quinepoxet and Stillwater rivers.*

QUINEPOXET RIVER AT HOLDEN.

[Parts per million. Averages by years.]

Year.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1892	Slight	6.2	0.194	0.014	0.001	0.088	1.9	37.0	9
1893	do	7.2	.192	.004	.001	.044	2.6	37.5	9
1894	do	6.1	.214	.041	.001	.027	2.9	38.5	7
1895	Very slight to distinct.	7.7	.289	.020	.003	.090	2.6	44.7	9
1896	do	6.4	.250	.012	.000	.045	1.9	37.4	4
1897	Very slight to decided.	7.7	.275	.032	.001	.055	2.1	38.8	8
1898	Slight	6.2	.248	.030	.001	.037	2.1	34.7	8
1899	Very slight to decided.	4.8	.261	.028	.001	.046	1.9	36.5	5
1900	do	5.1	.277	.036	.002	.047	2.1	38.8	5

STILLWATER RIVER AT STERLING.

1892	None to slight.	4.4	0.131	0.001	0.000	0.072	1.3	33.8	9
1893	do	5.0	.147	.006	.001	.002	1.8	34.5	7
1894	do	4.5	.137	.008	.000	.017	1.8	32.0	8
1895	do	5.2	.179	.008	.000	.051	1.9	34.8	9
1896	Very slight to distinct.	5.0	.229	.016	.000	.035	1.6	33.2	7
1897	None to very slight.	6.6	.199	.013	.000	.037	1.7	34.7	8
1898	do	5.1	.158	.008	.001	.026	1.6	30.2	8
1899	Very slight	3.1	.177	.020	.000	.050	1.7	32.4	5
1900	None to very slight.	3.3	.156	.025	.001	.025	1.5	30.7	7

South Branch of Nashua River at Clinton.—Just below the dam which marks the beginning of the restricted area above described the South Branch passes the town of Clinton, and there meets with its first important pollution. Flowing through Clinton from the west, Coachlace Brook enters the main stream. The large plant of the Lancaster Woolen Company, employing over 2,000 hands, contributes sewage and manufacturing refuse into the South Branch, and a small portion of the town also drains into this stream. Until September 15, 1899, the sewage of Clinton and an enormous quantity of wool-washing waste and other refuse from the extensive works of the *Bigelow Carpet* Company were discharged into Coachlace Brook.

In Table 15 is set forth results of four analyses of water from Coachlace Brook, which was at that time the foulest stream in the Nashua Basin.

TABLE 15.—*Analyses of water from Coachlace Brook.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Slight	3.5	0.620	2.280	0.056	0.180	10.0	96.5
Do	2.3	.520	2.200	.033	.330	9.5	89.0
Distinct	2.0	.710	1.720	.044	.200	9.9	94.5
Decided	4.0	.786	1.620	.200	.050	9.7	110.0
Average	2.9	.659	1.955	.083	.190	9.8	97.5

Character of water at Lancaster.—A short distance below this point is Lancaster, the place at which the North Branch enters. The quality of the water has been determined by a long series of analyses of samples taken at a point on the South Branch just above the confluence of the two rivers. The place was well chosen, for the water taken there shows the effect of the mixture of the water from Coachlace Brook and that running past the Lancaster mills, as above described.

TABLE 16.—*Analyses of water from South Branch of Nashua River above its confluence with North Branch at Lancaster.*

[Parts per million.]

Year.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1895	Very slight to distinct.	5.3	0.238	0.167	0.008	0.114	3.4	46.6	14	16
1896	Distinct	4.5	.216	.094	.006	.134	3.5	47.2	16	12
1897	Very slight to distinct.	6.0	.257	.092	.004	.110	3.2	44.7	13	12
1898	Very slight to decided.	5.0	.269	.327	.010	.098	3.3	47.7	13	12
1899	Very slight to distinct.	4.5	.415	1.026	.018	.087	7.5	73.4	17	12
1900	Very slight to decided.	3.3	.346	.537	.020	.392	10.0	77.3	19	12
1901	Decided	3.3	.331	.314	.012	.405	8.1	78.4	19	12

NORTH BRANCH OF NASHUA RIVER.

The North Branch of the Nashua is a good power stream and has been utilized extensively. Its flow is regulated to some extent by a series of reservoirs, but in spite of this the flow is variable. The total area of the basin is 127 miles, and the population is greater than that on the South Branch. The communities of Leominster and Fitchburg contain 44,000 inhabitants; both places support extensive manufacturing industries, and the pollution from household sewage and factory wastes is extensive. There are, nevertheless, many points in the watershed above these towns where the water is of excellent quality. Among these are Scott reservoir, which supplies Fitchburg, and Morse and Haynes reservoirs above Leominster, analyses of which are recorded in Table 7.

Normal water.—Still farther up in the drainage area is the Ashburnham storage reservoir, which conserves a normal water of a character indicated in the following report of analysis, it being the average of nine samples:

TABLE 17.—*Analysis of water from Ashburnham storage reservoir.*

[Parts per million.]

Turbidity	"None" to "distinct."
Color	None.
Residue on evaporation	25.2
Free ammonia	.008
Albuminoid ammonia	.077
Chlorine	a1.3
Nitrates	.191
Nitrites	.001

Above Fitchburg.—Taking the waters of Scott, Haynes, Morse, and Ashburnham reservoirs as normal, let us descend to a point a short distance above Fitchburg, where the pollution is merely that from a few factories in the vicinity of West Fitchburg.

TABLE 18.—*Analyses of water from North Branch of Nashua River above Fitchburg.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 19	Very slight	3.8	0.170	0.002	0.001	0.050	1.4	33.5	5
August 1	do	4.5	.182	.008	.000	.010	1.6	32.5	5
August 29	None	3.9	.170	.010	.000	.050	1.8	31.5	5
September 26	Slight	3.8	.216	.008	.001	.030	2.3	26.5	5
October 23	None	4.2	.192	.012	.000	.020	2.3	42.5	8
November 28	do	6.0	.178	.022	.000	.070	1.8	35.0	10
December 26	Very slight	4.5	.130	.012	.001	.130	1.8	36.0	8
Average		4.4	.177	.011	.000	.051	1.9	33.9	7

a Normal.

Except for a slight increase in the amount of chlorine the above analyses do not differ significantly from those in the normal reservoirs above noted. This difference is, however, an important one and bears unmistakable evidence of the pollution above noted.

Below Fitchburg.—Below Fitchburg the character of the water undergoes a marked change, as is indicated by the following series of analyses of samples taken at a point just below the city. It will be observed that, although the evidences of pollution are clear, they do not indicate the extremely foul character which was apparent in the waters of Coachlace Brook, on the South Branch.

TABLE 19.—*Analyses of water from North Branch of Nashua River below Fitchburg.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1893	5.7	0.360	0.461	0.018	0.118	6.9	74.6	20
1894	5.6	.346	.634	.020	.152	7.5	73.9	19
1895	5.9	.423	.832	.010	.134	7.5	81.0	22
1896	4.8	.499	.677	.017	.151	7.4	81.5	20
1897	6.1	.420	.370	.007	.120	6.1	68.2	18
1898	5.1	.467	.435	.009	.117	4.8	60.0	16
1899	4.3	.657	.967	.009	.069	7.2	76.2	18
1900	3.9	.660	1.011	.010	.072	9.7	81.0	20

Below Leominster.—Descending farther we come to Leominster, at which place enters a polluted stream known as Monoosnoc Brook, the characters of which are shown by the following statement, which is the average of ten analyses made in 1899 and 1900.

TABLE 20.—*Average of ten analyses of water from Monoosnoc Brook.*

[Parts per million.]

Turbidity	Decided.
Color	7.5
Residue on evaporation	49.9
Free ammonia	.280
Albuminoid ammonia	.444
Chlorine	4.3
Nitrates	.071
Nitrites	.0075
Hardness	12

At Lancaster.—Another series of analyses appears to have been made, the water being taken from the North Branch at a point just above its confluence with the South Branch. This point is also well chosen, as the river carries all the pollution which has entered above save that which has been oxidized or deposited in the course of the stream. Analyses of the water here show just what is contributed by the North Branch to the Nashua River system.

The following record covers six years, and can therefore be accepted as indicative of the true character of the water:

TABLE 21.—*Analyses of water from North Branch of Nashua River, just above its confluence with the South Branch at Lancaster.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	5.1	0.269	0.282	0.019	0.236	7.7	69.6	19
1896	4.7	.293	.217	.019	.155	5.5	61.6	18
1897	5.4	.290	.285	.008	.150	4.2	52.9	15
1898	4.5	.268	.222	.013	.168	4.4	50.7	15
1899	3.6	.316	.540	.016	.132	6.0	63.8	16
1900	3.1	.322	.501	.022	.152	6.6	63.4	18

A comparison of the results in Table 21 with the analyses of water from the South Branch, Table 16, shows that until 1899 North Branch was the more highly polluted.

During the years 1895–1898, inclusive, the amounts of free ammonia, nitrates, and chlorine in South Branch water were approximately 50 per cent of those in North Branch. After 1898 there appears to be a decided change in the character of the water in South Branch; organic ingredients increased remarkably and reached a maximum in the year 1900. It is evident that unusual conditions arose to produce this result. A history of the work of the Metropolitan Water Board of Massachusetts upon the South Branch of Nashua River shows that in March, 1898, a large proportion of the run-off water in the basin of South Branch above Clinton was diverted for use in the metropolitan district. This water had, up to this time, been efficient in diluting the refuse and sewage discharged from Clinton, and its withdrawal was immediately apparent in the condition of the stream below. Coincident with this diversion there was in progress the preparation of Wachusett reservoir; old dams were removed, the surface of the country was stripped of vegetation, and large amounts of water were

ned into the stream from foundation-wall excavations. The result s that the water which flowed past Clinton was made extremely rbid, and must have carried along in solution, as well as in suspen-on, great quantities of organic matter. These conditions are entirely ufficient to account for the change in the character of South Branch ater above its confluence with North Branch.

The unfavorable change in the character of the water in South ranch is only temporary. The beginning of an improvement took lace late in the fall of the year 1899, when the sewage of Clinton and he manufacturing wastes of the Bigelow Carpet Company were iverted into newly constructed purification works. The completion f Wachusett reservoir will mark the end of the operations which have ncreased the organic constituents in the river water and South Branch vill be restored to its former condition, or be greatly improved. Mr. F. P. Stearns, chief engineer of the Metropolitan Sewerage and Water Board, has expressed the belief that the above result will be eached in the fall of the year 1903, or early in the spring of 1904.

From Lancaster to Nashua, N. H.—We have now traced the pol-ution in the headwaters of the Nashua branches down to a point at which the main river takes its origin. From this point to Groton the river flows very sluggishly, and from Groton to a point 3 miles from its confluence with the Merrimac its fall is more rapid, becoming quite steep for the remainder of the course. From Lancaster to Nashua there is no settlement contributing important pollution. As the river sluggishly winds along its course it is increased in flow by other streams, notably the Squannacook at Ayer and the Nissitisset at Pepperell, so that when it reaches the latter place dilution, sedimenta-tion, and oxidation have had an effect which may be readily seen by examining the following reports of analyses:

TABLE 22.—*Analyses of water from Nashua River at Groton and Pepperell.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Place of collection.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
ay 22, 1895	Decided	4.0	0.164	0.014	0.003	0.170	4.0	48.5	16	Groton.
ug. 16, 1899	Slight	2.0	.264	.116	.014	.230	7.0	65.0	17	Pepperell.
ept. 21, 1899	Very slight	2.7	.230	.054	.012	.150	8.2	67.5	20	Do.
ct. 14, 1899	do	2.4	.236	.168	.004	.090	9.7	75.5	23	Do.
ar. 15, 1899	Decided	4.2	.264	.332	.003	.110	6.4	68.5	23	Do.
ly 16, 1900	Very slight	1.5	.200	.100	.005	.050	7.0	60.0	20	Do.
ug. 21, 1900	Slight	2.3	.258	.234	.018	.100	9.2	65.0	20	Do.

Flowing ever more swiftly it passes into the State of New Hampshire and emerges at Nashua in the Merrimac. The average of 19 analyses made during the years 1887–88 appear below. The samples were taken at Mine Falls, above Nashua pollution.

TABLE 23.—*Average of nineteen analyses of water from Nashua River at Mine Falls.*

[Parts per million.]

Turbidity	Slight to decided.
Color	3.8
Residue on evaporation	45.8
Free ammonia	.029
Albuminoid ammonia	.187
Chlorine	[a]2.9
Nitrates	.102
Nitrites	.008

OTHER TRIBUTARIES OF THE MERRIMAC.

Outside of the State of Massachusetts the character of the waters of the Merrimac drainage area is almost unknown. The New Hampshire laboratory of hygiene has not yet been established for a time sufficient to allow extensive investigations. It is probable that in due time this laboratory will complete the work which has been carried on by the State Board of Health of Massachusetts.

Piscataquog and Contotook rivers.—No analyses are available of the water of the Piscataquog or Contotook. It is safe to assert that neither stream is polluted to any extent, for there are no important settlements in the valleys. The population in the basin of the Contotook is only 31.4 per square mile.

Lake Winnepesaukee.—The water of Lake Winnepesaukee has been analyzed by the Massachusetts State Board of Health for the purpose of determining its fitness as a source of supply for the metropolitan district. The average is included in Table 7.

Pemigewasset River.—The Pemigewasset Valley, which lies at the head of the Merrimac system, has a population of 17 per square mile. No sewerage systems enter the river, nor are there any large centers of population. The supply of water to the Merrimac is therefore pure and abundant. The only available analysis has been kindly furnished by Mr. H. E. Barnard, chemist of the New Hampshire laboratory of hygiene. The place of collection was at Campton Village, at the extreme southern end of the basin. It therefore fairly represents the character of the water furnished by the Pemigewasset drainage area to the Merrimac.

[a] Chlorine 1.4 above normal.

BLE 24.—*Analysis of water from Pemigewasset River at Campton, N. H.*

[Parts per million.]

ppearance.			Ammonia.				Chlorine.	Nitrogen as—		Hardness.
bidity.	Color.	Total residue on evaporation.	Free.	Albuminoid. Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.	
e	4.0	34	0.016	0.094	.....	.....	0.637	0.100	0.100	....

OLLUTION OF MERRIMAC RIVER AT MANCHESTER, NASHUA, LOWELL, LAWRENCE, AND HAVERHILL.

Having considered the characteristics of the water in the tributaries ich have received attention from analyses, let us review the work ich has been done in the Merrimac proper and show, as closely as ssible with the data at hand, how each tributary affects the river; o the changes due to the extensive pollution which arises from the ies along the bank.

Manchester.—We have said that the upper part of the Merrimac ea is sparsely settled, and that such analyses as are available show at the water is pure. From the Contoocook, Pemigewasset, and innepesaukee drainage basins there is delivered into the Merrimac reat volume of water, which is increased by the numerous smaller butaries which enter all along the course. It is not likely that it anges greatly in character until it reaches Manchester, N. H., an portant manufacturing city of 56,987 inhabitants. Sewage and anufacturing wastes are poured directly into the river, and, although ere are at hand no analyses to show the exact condition of the wate , is certain that the change is marked.

Nashua.—Sixteen miles below, at the city of Nashua, a series of alyses has been furnished by Mr. Barnard which shows the effect Manchester pollution after it has been carried along for the above stance. It is at this point that the abundant flow of Nashua River ters the Merrimac, dilutes still further the Manchester pollution, d renders the sewage from Nashua, a city of 23,898 inhabitants, s damaging than it would be under conditions not so favorable.

TABLE 25.—*Average of nineteen analyses of water from Merrimac River at Nashua.*

[Parts per million.]

Appearance.			Ammonia.				Chlorine.	Nitrogen as		Hardness.
Turbidity.	Color.	Total residue on evaporation.	Free.	Albuminoid. Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.	
ight.....	3.4	50.1	0.014	0.153	.....	.....	1.5	0.074	0.002	6.0

Lowell.—Leaving Nashua, the river crosses the State line, and when it reaches a point opposite the old water intake at Lowell it is of a quality shown in the following analysis:

TABLE 26.—*Analyses of water from Merrimac River above Lowell.*

[Averages by years, monthly samples. Parts per million.]

Years.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	3.0	0.148	0.016	0.002	0.099	1.6	34.2	.....
1889	2.8	.149	.018	.002	.071	1.4	29.5	.....
1890	3.0	.128	.014	.001	.111	1.3	35.7	14
1891	2.9	.129	.017	.001	.137	1.3	34.3	12
1892	3.9	.141	.021	.001	.092	1.4	36.1	13
1893	3.3	.149	.026	.001	.082	1.0	33.9	11
1894	3.5	.135	.024	.001	.063	1.8	35.5	11
1895	4.1	.187	.029	.001	.066	2.1	38.4	12
1896	4.0	.167	.024	.001	.070	1.7	34.7	10
1897	5.1	.177	.030	.001	.067	1.5	35.4	10
1898	4.2	.173	.026	.001	.048	1.7	35.3	10
1899	2.7	.287	.050	.002	.060	1.8	36.0	9
1900	2.7	.297	.052	.002	.047	1.9	35.5	11

The water represented in the series of analyses above set forth was formerly used in its raw state as the principal water supply for the city of Lowell. The history of that municipality during this period furnishes to the world one of the clearest illustrations of the cost of water pollution extant, and it stands among epidemiologists as one of the classical examples of disease production through polluted water supply. No history of typhoid fever is complete without an account of the Lowell epidemic. For years the typhoid rate was abnormal, but little attention was given to it until the year 1890, when there occurred from September of that year to January, 1891, a series of 550 cases. Prof. William T. Sedgwick, in a remarkable investigation, traced the origin of the epidemic to a few individuals who, while in the prodromal stage of typhoid fever, had polluted a small brook which enters the Merrimac a short distance above Lowell.

The pecuniary damage caused by polluted water throughout all the years in which the Merrimac was used as a source of supply will never be even approximately estimated. In the epidemic of 1890 alone there was a loss of 92 lives. In addition to this there was the expense incident to the care of 550 cases of the disease and the temporary loss of productiveness of all those who escaped death. The greater part

of this drain upon the resources of the community was without a shade of justification; it might have been prevented by the exercise of municipal decency. After the lesson had been learned, the city of Lowell was obliged to add to the total expense by constructing a new supply, the cost of which will be borne by generations yet unborn.

As the Merrimac passes by Lowell its burden of sewage is increased by the addition of wastes from 95,000 persons and from enormous mills and factories.

Lawrence.—Flowing 9 miles farther the river reaches the city of Lawrence, and there, opposite the intake of the works, the water has a character denoted by the following series of annual averages, each average being the result of monthly analyses:

TABLE 27.—*Analyses of water from Merrimac River above Lawrence.*

[Parts per million.]

Year.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	3.0	0.180	0.026	0.002	0.094	1.8	36.8	
1889	3.0	.176	.030	.003	.072	1.7	30.9	
1890	3.3	.166	.046	.001	.089	1.7	31.9	16
1891	2.7	.152	.040	.001	.110	1.8	37.9	13
1892	4.3	.181	.042	.001	.105	1.8	41.2	14
1893	4.2	.181	.057	.002	.081	2.0	38.6	11
1894	3.7	.167	.062	.001	.063	2.3	37.0	12
1895	5.1	.249	.064	.002	.071	2.8	43.1	14
1896	4.2	.220	.068	.003	.087	2.4	39.8	12
1897	5.6	.228	.049	.001	.067	2.0	38.4	11
1898	4.5	.212	.050	.003	.058	2.2	39.0	11
1899	2.9	.232	.088	.003	.056	2.4	39.9	10
1900	3.0	.224	.089	.002	.060	2.5	39.6	11

The history of the Lawrence water supply and the consequences of its use closely resemble those already described at Lowell, and, indeed, the account of the events in the two cities is generally combined. For years the raw water from the Merrimac was pumped into the Lawrence mains. Following the discharge of typhoid-infected stools from the sewers at Lowell there arose a widespread epidemic in the lower city. In Lawrence the source of supply was not changed, but the first sand filter in the country was established at a cost of $65,000. Through this filter the water of Lawrence is now drawn at an annual expense of $8,000 or $9,000, the result being that the typhoid-fever rate in the city has been considerably lowered.

A comparison of the water after it has been passed through tl filter with that in the river is instructive. For this purpose the f lowing analyses are presented, each being the average of 12 month samples:

TABLE 28.—*Analyses of the effluent of the Lawrence filter.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Ha ne
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	3.9	0.094	0.103	0.002	0.309	3.0	61.0	
1895	5.0	.108	.146	.001	.274	3.1	59.5	
1896	4.0	.099	.121	.004	.319	2.5	54.3	
1897	5.6	.108	.123	.002	.317	2.5	51.7	
1898	4.3	.090	.107	.001	.324	2.6	46.6	
1899	2.7	.089	.087	.001	.205	2.8	44.4	
1900	2.8	.108	.123	.001	.173	2.7	43.0	

TABLE 29.—*Increase in amount of impurities in Merrimac River water from point above Lowell to Lawrence, as determined by regular monthly examinati in different years.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue	Ha ne
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1887–1889	0.1	0.027	0.007	0.000	a0.003	0.026	2.3	
1890	.5	.023	.016	.000	a.020	.280	6.2	
1891	a.2	.023	.021	.000	a.030	.350	2.9	
1892	.6	.027	.019	.000	a.013	.390	4.8	
1893	.9	.032	.031	.001	a.002	.350	4.7	
1894	.2	.032	.028	.000	.000	.490	1.5	
1895	1.1	.063	.022	.001	.005	.630	5.2	
1896	.2	.053	.034	.002	.017	.700	5.1	
1897	.6	.051	.019	.000	.000	.500	3.0	
1898	.3	.039	.024	.002	.010	.440	3.7	
1899	.2	.045	.038	.001	a.004	.590	3.9	
1900	.3	.027	.037	.000	.011	.550	4.1	

a Decrease.

At Lawrence the sewage from 63,000 persons and extensive manufacturing wastes are poured into the Merrimac. Thence the river flows 8 miles to Haverhill.

Haverhill.—Above Haverhill there were, from July to November, 1900, five samples taken, the reports of analyses being as follows:

TABLE 30.—*Analyses of Merrimac River water above Haverhill.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	2.3	0.288	0.192	0.004	0.010	3.9	46.5	13
Aug. 21	Decided	1.5	.316	.144	.008	.050	3.9	44.0	16
Sept. 18	Slight	1.5	.328	.272	.009	.020	4.8	50.0	13
Oct. 30	do	3.4	.360	.296	.010	.100	4.4	53.5	14
Nov. 20	Decided	6.5	.328	.144	.003	.080	3.3	53.0	16
Average		3.0	.324	.210	.007	.052	4.1	49.4	14

Haverhill sewage is discharged into the Merrimac. This city has a population of 31,175. Analyses of the water from the river, collected a short distance below the city, are reported by the State Board of Health as follows:

TABLE 31.—*Analyses of Merrimac River water below Haverhill.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	2.0	0.324	0.284	0.007	0.010	4.2	44.0	14
Aug. 21	Decided	1.5	.276	.220	.010	.020	3.7	45.0	17
Sept. 18	Slight	2.3	.375	.265	.017	.040	5.7	55.0	16
Oct. 13	Decided	3.5	.360	.264	.011	.090	4.4	54.0	11
Nov. 20	do	6.6	.340	.136	.004	.120	3.2	53.5	14
Average		3.2	.335	.311	.010	.050	4.2	50.3	12

BLACKSTONE RIVER.

COURSE, CHARACTER, AND UTILIZATION OF THE STREAM.

Blackstone River is a small stream which rises in Worcester County Mass., and flows in a southeasterly direction, passing over the Stat line into Rhode Island and emptying into the Providence River a Providence. Its drainage area covers about 458 square miles. A the source the elevation is 438 feet above mean tide and as its cours is about 43 miles long its fall must be somewhat more than 10 fe per mile. It is obvious that such a river, so accessible, and in th midst of a populous country, must have unusual value as a source c power. This fact has long been recognized and the stream has bee thus utilized, the natural facilities being enhanced by the develo ment of every accompaniment known to be of use in a river of thi character. Probably no stream in the United States has been s effectively harnessed and brought into subjugation; milldams hav been erected at favorable points, compensating reservoirs have bee constructed, and ponds and lakes have been raised in order that th flow may be regulated to meet the demands of manufacturing. Th result is that though the river is derived from a watershed which ha been extensively deforested, and, under ordinary circumstances would be subject to floods and variation in flow, its water is seldo allowed to fall below a certain minimum because of the judicio management of the conserved water during dry seasons. The gre resource of this stream is, therefore, its water power, and it has bee said with authority that the value of this interest is proportionate greater than that found in any other stream in the United States.

POPULATION OF THE BASIN.

Population.—The Blackstone River (see fig. 6) is formed by t junction of Kettle and Mill brooks in the southern part of the city Worcester. These two brooks drain small parts of the towns Holden and Leicester, as well as Worcester. The other Massachuse towns in the basin are Auburn, Millbury, part of Shrewsbury, Gra ton, Upton, Sutton, Northbridge, Hopedale, Mendon, Douglass, U bridge, and Blackstone, representing a population of about 157,0 or 604 per square mile. In the State of Rhode Island the river drai the municipalities of North Smithfield, Burrillville, Gloucester, Woo socket, Lincoln, and Cumberland, having a combined population 56,267.

This large population is mostly in the northern part of the draina area, at Worcester, Mass., which has a population of 118,421. T population per square mile therefore decreases as the mouth of t river is approached. This fact was well expressed in the report the Massachusetts Board of Health in 1890, as follows:

TABLE 32.—*Population in drainage basin of Blackstone River.*

Locality.	Distance below discharge of Worcester sewage.	Drainage area (square miles.)	Population, estimated (1888).	Population per square mile.
	Miles.			
the Quinsigamond Iron and Wire Works	0	63.0	.....	.....
the first bridge below Quinsigamond village	1	63.9	77,500	1,213
the dam of the Cordis Co., Millbury	5	77.9	.....	.....
the upper dam of the Calumet Woolen Co., Uxbridge	17	145.9	90,900	623
the Middleville dam, Blackstone	24	258.1	102,800	398
the dam of the Blackstone Manufacturing Co., Blackstone	26	260.3	.....	.....

e the collection of the facts in the table the city of Worcester own faster than the lower towns in the valley, making the cons above set forth even more extreme.

FIG. 6.—Blackstone River drainage basin.

NORMAL WATER IN THE BASIN OF THE BLACKSTONE.

Normal water in the basin of the Blackstone has been found at the head of Kettle Brook, Paxton, Lynde Brook storage reservoir in Leicester, and Tatnuck Brook storage reservoir in Holden.

TABLE 33.—*Analyses of normal water in Blackstone Basin.*

LYNDE BROOK STORAGE RESERVOIR.

[Parts per million, averages by years.]

Year.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.
1888	2.4	0.151	0.037	0.001	0.065	1.4	26.4	....
1889	2.4	.167	.030	.001	.053	1.5	25.4	....
1890	2.1	.132	.026	.001	.078	1.4	30.7	9
1891	2.4	.126	.045	.001	.074	1.2	28.3	7
1892	2.5	.139	.038	.000	.105	1.5	29.9	8
1893	2.6	.162	.036	.001	.066	1.5	26.6	6
1894	3.6	.139	.055	.000	.103	1.8	33.7	12
1895	3.2	.161	.033	.000	.116	2.0	36.3	13
1896	2.9	.158	.035	.000	.054	1.8	29.5	8
1897	4.4	.191	.068	.001	.087	1.8	33.1	8
1898	3.1	.156	.030	.001	.059	2.0	32.4	8
1899	2.0	.147	.030	.000	.031	1.2	24.9	4
1900	2.3	.176	.043	.000	.039	1.4	29.2	7
KENT RESERVOIR, KETTLE BROOK.								
1898	3.6	0.176	0.012	0.001	0.042	1.6	32.0	8
1899	2.7	.239	.047	.001	.037	1.3	32.5	7
1900	3.2	.213	.037	.001	.064	1.7	32.0	8
TATNUCK BROOK RESERVOIR.								
1888	1.7	0.157	0.012	0.001	0.043	1.2	22.3	....
1889	1.9	.143	.003	.001	.031	1.2	20.4	....
1890	1.7	.141	.007	.001	.078	1.3	26.8	9
1891	1.7	.143	.024	.001	.077	1.1	23.0	4
1892	2.0	.142	.012	.000	.067	1.2	25.2	5
1893	3.5	.182	.020	.000	.049	1.4	24.5	5
1894	2.0	.151	.010	.000	.032	1.6	22.7	4
1895	2.1	.173	.012	.000	.068	1.8	23.3	5
1896	1.7	.142	.008	.000	.034	1.5	20.0	4
1897	2.1	.155	.007	.000	.054	1.6	21.2	5
1898	2.2	.141	.006	.000	.020	1.6	22.4	5
1899	1.1	.136	.013	.000	.016	1.2	20.0	2
1900	1.5	.186	.026	.000	.023	1.2	22.7	2

POLLUTION IN BLACKSTONE RIVER.

Blackstone is the most polluted river in New England; its
is become synonymous with filth. The headwaters of a river
are usually free from pollution, but in this case the opposite
The sewage from the city of Worcester befouls the river
it its source, and thereafter throughout its whole extent the
one is a damaged resource to the country. Such is the accumu-
f filth in the mill ponds that from some of those near Worces-
e arise odors that are detrimental to comfort and realty, if
ealth. The use of its water in boilers has long been aban-
nd it can not be used in the manufacture of light-colored

ester sewage.—The sewage of Worcester, consisting of the usual
ite and an enormous amount of manufacturing refuse, a large
which is acid from the steel manufactories, is turned from the
nto Mill Brook. The quantity is sufficient at times to give to
ers of the Blackstone River an acid reaction.
ater of Mill Brook above the point of sewage discharge has
n regularly examined, but it is known to be of a quality char-
ic of a stream flowing through a country of considerable popu-
nd approaching in some degree the character of the normal
above set forth. After being polluted with the Worcester
the water of Mill Brook is of a vile character, as is shown in the
g table of averages of monthly analyses for the years 1888–1900.

—Analyses of water from Blackstone River below mouth of Mill Brook and above outlet of sewage works.

[Parts per million.]

ear.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
.....	6.4	1.040	2.112	0.029	0.370	12.1	.....	.....
.....	7.6	1.198	2.841	.024	.235	10.6	.....	.....
.....	8.2	1.024	1.800	.014	.367	10.3	.....	.....
.....	8.0	1.563	3.340	.032	.333	17.3	135.4	46
.....	7.1	1.262	2.530	.061	.312	18.4	162.8	49
.....	6.8	.603	1.429	.012	.180	10.4	179.5	45
.....	8.6	.570	.739	.006	.195	8.8	171.7	37
.....	8.4	.374	.507	.007	.175	8.6	134.0	29
.....	7.5	.486	.759	.010	.187	10.1	126.9	29
.....	9.4	.533	.715	.015	.151	7.7	176.2	20
.....	5.0	.557	.762	.011	.167	8.3	135.2	35
.....	2.6	.751	1.921	.010	.109	12.0	253.3	97
.....	1.8	.602	1.141	.011	.102	8.3	104.9	62

For years the city of Worcester has converted Mill Brook into an open sewer, and up to June 25, 1890, the contents were discharged directly into Blackstone River. At that time, however, a chemical precipitation works was completed by the city, and by means of a diverting dam the whole flow of Mill Brook, except during seasons of freshet, was carried across to a series of tanks, six in number, each being 100 feet long, 66.76 feet wide, and 7 feet deep. The capacity of these tanks for the treatment of sewage, according to the process adopted, was 6,000,000 gallons daily. In the year 1883 ten more tanks were added to the original six, which gave to the disposal works a nominal capacity of 15,000,000 gallons per day.

The treatment of sewage was first as follows: After being screened it was mixed with chemicals, and, passing through a mixing channel, it fell into the precipitation tanks, discharging from the first to the second, and so on through the whole series, finally being poured into the Blackstone River. The chemicals used were lime and sulphate of alumina, the former being required in large quantities when the sewage was greatly impregnated with iron. After the enlargement of the works in 1893 the process was changed slightly, the object being to secure a more thorough mixture of chemicals with the sewage before it passed into the precipitation tanks. During the year ending November 30, 1901, 3,564.7 million gallons of sewage were received at the disposal works, of which 3,133.8 million gallons were treated chemically and the remainder used for experimental work in connection with new processes of sewage disposal. The total cost of this treatment was $12.20 per 1,000,000 gallons. The chemical precipitation of sewage at Worcester is not, however, successful from the standpoint of river purification, and very little if any benefit has been apparent in the river throughout all the years during which this great expenditure has been incurred by the city. Finally the legislature of the State enacted a law requiring the city to dispose of its sewage by some other method, and experiments are now being conducted to determine a method which will effect a more satisfactory purification of Blackstone River.

Below sewage-disposal outlet.—The next recorded point of examination of the Blackstone is below the sewage precipitation works. The point of collection of the samples is nearly a mile below the mouth of Mill Brook and a considerable distance below the outlet of the precipitation works, so that the effluent has had ample opportunity to become thoroughly mixed with the river water. The following is a list of annual averages of monthly examinations during the period 1888–1900.

5.—*Analyses of water of Blackstone River below Worcester sewage-disposal outlet.*

[Parts per million.]

Year.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
	6.4	1.040	2.122	0.029	0.370	12.1		..
	7.6	1.198	2.894	.024	.235	10.6	..	..
	7.4	1.177	2.253	.016	.381	12.6		..
	8.0	1.303	4.080	.031	.358	19.1	156.2	46
	5.3	1.442	3.633	.033	.278	22.1	193.5	72
	7.4	1.447	3.757	.070	.369	19.8	256.5	74
	6.0	1.300	4.228	.047	.316	21.3	257.5	79
	7.9	.840	2.298	.040	.347	15.2	191.4	58
	4.0	.930	2.645	.071	.356	19.1	242.8	83
	7.5	.843	2.447	.047	.300	13.3	199.4	54
	4.9	.725	2.260	.072	.264	13.0	194.1	66
	3.0	1.337	3.908	.053	.176	28.7	324.8	120
	2.5	1.249	4.430	.145	.110	21.3	224.7	73

parison of the analyses in Tables 34 and 35 shows clearly that, : of the so-called sewage purification carried on at Worcester great an expense, Blackstone River is in far worse condition he sewage outlet than above. The amounts of free ammonia, , and chlorine at the lower sampling point are considerably than above the outlet of the purification works. In addition there are unmistakable evidences that the amount of objec- e matter from the outlet is increasing from year to year, while ditions above constantly improve.

idge.—Again there appears a record of examinations of sam- ken from the river at the upper dam of the Calumet Woolen ny at Uxbridge, 17 miles below the city of Worcester. The es were made monthly during the period 1888–1900, but in Table results are made up into yearly averages, as in the preceding 34 and 35.

TABLE 36.—*Analyses of water from Blackstone River at Uxbridge.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	4.5	0.284	0.979	0.008	0.322	6.1	.....	....
1889	2.8	.300	.992	.009	.253	6.0	.....	....
1890	2.5	.214	1.168	.006	.272	6.6	.....	....
1891	2.7	.272	1.674	.008	.396	7.7	83.2	26
1892	2.1	.222	2.113	.007	.326	8.2	85.9	28
1893	4.0	.256	1.603	.029	.424	10.0	94.5	33
1894	5.1	.242	1.372	.032	.460	12.2	108.0	40
1895	6.4	.315	1.081	.037	.439	10.5	105.6	39
1896	4.2	.308	1.209	.054	.405	10.9	107.7	42
1897	5.9	.298	1.126	.035	.481	10.4	103.1	38
1898	5.8	.305	.818	.046	.360	8.4	87.2	33
1899	2.6	.374	2.298	.078	.331	15.9	140.6	56
1900	2.7	.351	2.122	.039	.359	13.8	114.3	42

It will be seen that sedimentation, dilution, and oxidation have worked improvement in the water by the time it has traversed the 17 miles, although the process during late years does not appear to be as effective as formerly. It requires only a glance to perceive that the pollution of the Blackstone is still enormous. Be it remembered, too, that, apart from the pollution at Worcester, the numerous mills along the course of the stream and the large number of employees there engaged contribute a great quantity of sewage and foul industrial waste, which of itself would be damaging to the river. Therefore the comparison of the two sets of analyses above given does not furnish an idea of the normal self-purifying ability of the river, for it is more than probable that there would appear a greater decrease in the amount of organic matter if it were not for the constant introduction of new pollution.

At Millville.—Down the river, nearly to the State line at Millville, town of Blackstone, a series of analyses similar to the one at Uxbridge has been carried on for thirteen years. This point is 24 miles from the Worcester outlet and the water is not objectionable in odor. Still, as the following analyses show, the water is polluted.

om the rolling surface common to Massachusetts to the hilly tainous country of New Hampshire and Vermont. The rocks ite, gneiss, syenite, and mica, intersected by dikes of trap sandstone. Along the course of the river in Massachusetts necticut there are rich alluvial deposits, but for the most part of the Connecticut is covered by surface drift. Lakes are abundant on most of the branches, and the flow of the main river is fairly steady.

. 7. Connecticut River drainage basin.

The course of the Connecticut is varied. From its source for a distance of 200 miles downstream the river contains many falls and rapids, the last one being at Bellows Falls, Vt. Below this place the fall in the stream is much less, yet the pitch is sufficient to give the water a fairly good flow. Throughout the extent of the river below Bellows Falls the course of the river is broken by falls in three places, Turners Falls and Holyoke, Mass., and Windsor Locks, Conn. The power developed at Holyoke is the largest in the country, except that at Niagara.

Transportation. — The river has considerable importance in the lower end as a means of transportation. Navigation extends 30 miles from the mouth up to Hartford, and small boats may ascend, by of Windsor Locks, as far as Holyoke. Travel, however, above d is insignificant, while even in the lower stream large vessels fficulty in low tide.

r.—As a source of power the value of the Connecticut is enor- *The main river, with a* total fall of 2,038 feet, has been largely *but there remain* possibilities for further development which,

TABLE 38.—*Analyses of water from Blackstone River at Albion and Valley Falls, R. I.*

ALBION.

[Average by years, in parts per million.]

Year.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	0.235	0.156	0.040	0.800	11.0	75	21.7
1895	.260	.127	.....	.560	10.5	81	21.3
1896	.220	.204	.030	.780	.9	72	16.0
1897	.220	.223	.030	.650	7.7	75	14.0
VALLEY FALLS.							
1894	0.261	0.117	0.070	0.824	12.0	66.5	17.6
1895	.201	.139	.070	.500	10.8	69.0	22.4
1896	.200	.196	.070	.070	.9	85.0	16.0
1897	.220	.215	.040	.070	.8	74.0	15.0

The results expressed in Table 38 do not inspire confidence in their accuracy, and it is highly probable that the tables presented in the report of the State Board of Health for 1897 are typographically incorrect. On comparing the results with those taken from the Massachusetts reports it will be seen that the nitrites are enormously high, averaging greater than the amounts found below the Worcester sewage outlet. It is extremely unlikely that these results are correct, because of the fact that the water shows decided improvement as it flows from Worcester town to the Rhode Island line, and south of that there is no increment of sewage which would by any means give to the nitrites the enormous figure which appears in the above analyses. The chlorine determinations, too, show improbable fluctuations.

On the other hand, the amounts of free and albuminoid ammonia, which would necessarily fluctuate to some extent at least with the nitrites and nitrates, do not appear excessive.

CONNECTICUT RIVER BASIN.

NATURAL RESOURCES.

Course and drainage area.—The Connecticut is the largest river in New England. From its source in the Connecticut lakes in the extreme northern part of New Hampshire to its mouth in Long Island Sound the course of the river measures 375 miles. The drainage area is long and narrow, being from 40 to 60 miles in width and covering 10,924 square miles (see fig. 7). The character of the country

rom the rolling surface common to Massachusetts to the hilly ntainous country of New Hampshire and Vermont. The rocks nite, gneiss, syenite, and mica, intersected by dikes of trap l sandstone. Along the course of the river in Massachusetts nnecticut there are rich alluvial deposits, but for the most part in of the Connecticut is covered by surface drift. Lakes are abundant on most of the branches, and the flow of the main river is fairly steady.

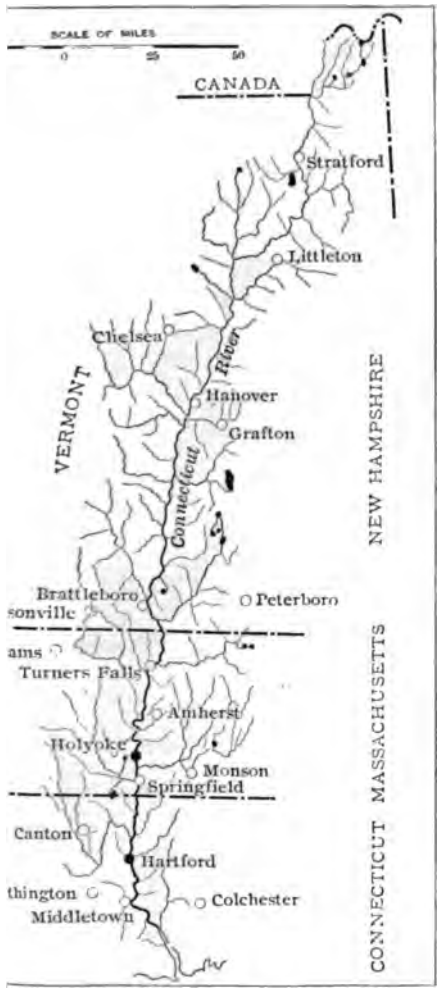


Fig. 7. Connecticut River drainage basin.

The course of the Connecticut is varied. From its source for a distance of 200 miles downstream the river contains many falls and rapids, the last one being at Bellows Falls, Vt. Below this place the fall in the stream is much less, yet the pitch is sufficient to give the water a fairly good flow. Throughout the extent of the river below Bellows Falls the course of the river is broken by falls in three places, Turners Falls and Holyoke, Mass., and Windsor Locks, Conn. The power developed at Holyoke is the largest in the country, except that at Niagara.

Transportation. — The river has considerable importance in the lower end as a means of transportation. Navigation extends 30 miles from the mouth up to Hartford, and small boats may ascend, by is of Windsor Locks, as far as Holyoke. Travel, however, above ford is insignificant, while even in the lower stream large vessels difficulty in low tide.

wer.—As a source of power the value of the Connecticut is enor- s. The main river, with a total fall of 2,038 feet, has been largely ized, but there remain *possibilities* for further development which,

if advantage were taken of them, would make the Connecticut of the most valuable streams in the world. The tributaries been developed extensively, and the possibilities for the future promising.

In the following table, taken from Water-Supply and Irrig Paper No. 44, there is presented a detailed statement of the alti and fall per mile at different points along the river:

TABLE 39.—*Fall of Connecticut River.*

Locality.	Distance from mouth.	Height above sea.	Fa n
	Miles.	*Feet.*	F
Mouth	0	0	...
Hartford	50	0	...
Foot of Enfield Rapids	60	6	
Top of Enfield dam	66	38	
Top of Holyoke dam	84	98	
Fitchburg Railroad crossing	115	109	
Top of Turners Falls dam	120	173	
Mouth of Ashuelot River	136	206	
Westmoreland	159	219	
Foot of Bellows Falls	170	234	
Head of Bellows Falls	170	283	...
Beaver Meadows, Charlestown	181	289	
Windsor	196	304	
White River Junction	209	339	
Ledyard bridge, Hanover	213	375	
Oxford	230	380	
Wells River	255	407	
Foot of McIndoes Falls	262	432	
Lower Waterford	273	643	
Head of Fifteenmile Falls	285	830	
North Stratford	312	885	
West Stewartstown	344	1,035	
Connecticut Lake	361	1,618	
Second Lake	369	1,882	
Third Lake	375	2,038	

The following table contains a statement of the total utilized h power and the drainage area of the most important tributaries o Connecticut.

TABLE 40.—*Drainage area and utilized horsepower on the Connecticut River tributaries.*

Tributary.	Horse-power utilized.	Drainage area.	Tributary.	Horse-power utilized.	Drainage area.
		Sq. miles.			*Sq. miles.*
Salmon River	1,432	150	Ottaquechee River	1,723	192
Hockanum River	3,957	79	Mascomy River	1,576	190
Little River	555	76	White River	2,714	623
Farmington River	8,856	584	Ompomponoosuc River	493	123
Scantic River	1,122	118	Waits River	596	156
Westfield River	3,910	514	Lower Ammonoosuc River	2,526	388
Chicopee River	4,044	706	Wells River	628	94
Mill River	1,161	58	Passumsic River	4,724	435
Deerfield River	4,352	646	Johns River	168	86
Millers River	8,172	369	Israels River	974	129
Ashuelot River	3,964	422	Upper Ammonoosuc River	548	252
West River	1,947	363	Nulhegan River	240	132
Williams River	361	103			
Black River	2,132	152			
Sugar River	3,176	272			

FLOW.

The flow of the river has been carefully measured and a concise statement appears in Part IV of the Twentieth Annual Report of the United States Geological Survey, page 47.

TABLE 41.—*Flow of the Connecticut River at Holyoke during the years 1880–1898, inclusive.*

[Drainage area, 8,000 square miles.]

Year.	Maximum.	Minimum.	Mean.	Run-off.	
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*	*Inches.*
1880	44,100	300	8,343	0.96	12.89
1881	49,050	450	9,818	1.13	15.53
1882	45,000	250	10,018	1.14	15.40
1883	68,300	250	8,107	.94	12.70
1884	71,900	500	13,084	1.51	20.46
1885	63,950	2,950	12,635	1.46	19.65
1886	80,150	550	11,387	1.31	17.73
1887	85,500	3,300	14,329	1.65	21.32
1888	99,750	1,100	17,320	2.00	27.15
1889	37,650	1,350	13,903	1.59	21.50
1890	46,750	550	15,556	1.78	24.12

TABLE 41.—*Flow of the Connecticut River at Holyoke, etc.*—Continued.

Year.	Maximum.	Minimum.	Mean.	Run-off.	
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*	*Inches.*
1891	67,300	900	13,190	1.51	21.48
1892	63,100	1,800	12,273	1.48	20.15
1893	94,350	750	10,295	1.19	16.19
1894	43,300	150	8,397	.97	13.17
1895	115,000	350	10,314	1.20	16.19
1896	112,050	450	12,394	1.43	19.41
1897	75,350	1,300	15,373	1.78	24.17
1898	76,150	600	13,844	1.60	21.70

Water supply.—Although a comparatively small part of the drainage area of the Connecticut has been set apart and developed as a source of water supply, the value of the resources within its basin are readily apparent. None of the cities along the main stream pump their supply from the river direct, but in the areas of the tributaries numerous reservoirs have been constructed from which are obtained water supplies of excellent quality. These will be taken up in the discussion of the different branches.

Ice.—The ice values in the Connecticut system are extensive. The same statements that were made in connection with this subject in the discussion of the Merrimac apply here. The main river has not been used largely as a source of ice supply. That it would be more acceptable than some rivers, as the Hudson, Kennebec, and Penobscot, which have been largely developed in this direction and yield enormous amounts annually, is very probable, yet it is the practice of the consumers in the Connecticut Valley to refuse to accept ice from the main stream. Therefore the small streams, ponds, and lakes within convenient distances from each municipality have been utilized. There is no estimate of the value of the ice crop in the Connecticut basin.

Character of water.—The character of water in the main river is of course largely determined by that from the tributaries feeding it, and as the water in the latter varies widely in different regions, that in the Connecticut proper is dependent upon the distance of a given sampling point from the confluence of a normal or a polluted branch. Below the entrance of a tributary loaded with sewage and manufacturing wastes the condition of the water is inferior to that at a point where it has been diluted by an influx of pure water from an unpolluted tributary.

Little or no attention has been given to the tributaries entering *the main artery* above the Massachusetts State line, and the highest *branch concerning* which we have information is Millers River.

MILLERS RIVER.

Millers River (see fig. 8) enters the Connecticut from the east at a int in Massachusetts about 10 miles south of the New Hampshire e. Its basin adjoins that of the Chicopee on the south and extends r into the State of New Hampshire on the north, covering about square miles. The drainage area is hilly, especially near the er's confluence with the Connecticut, but farther back there are ge areas of flat land. Lakes and ponds are plentiful, having a al area of 3,200 acres.

The flow of the river is very steady and its consequent value as a wer stream is large. From Winchendon, near its headwaters, to mouth there is a fall of 775 feet, the distance being not more than miles. All of this fall is not available for development, however,

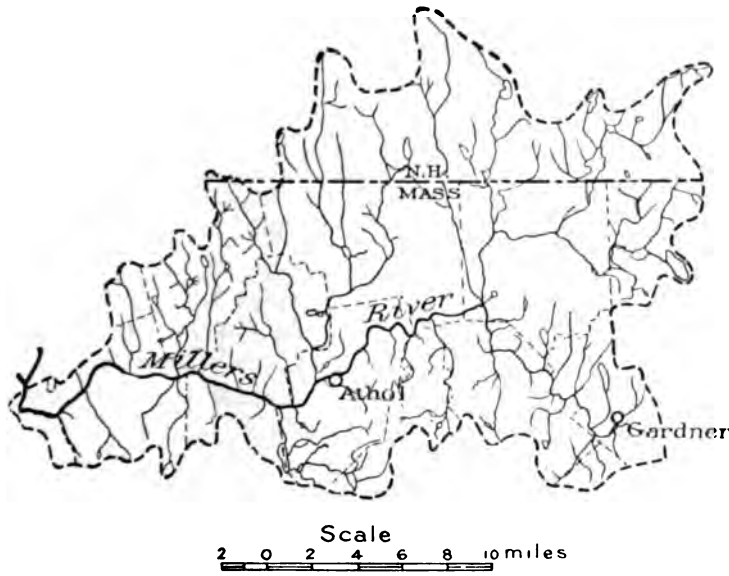


FIG. 8.—Millers River drainage basin.

s the course of the river for considerable distances partakes of the ature of a ravine; the banks are high and steep and little opportunity is afforded for the establishment of mills. The only available ow measurements are those made during October, November, and ecember, 1887, at the dam of the New Home Sewing Machine Company, at Orange. During this period the average monthly flow varied om 1.10 to 1.45 cubic feet per second per square mile. The population in the basin of Millers River is about 96 per square mile. This, owever, does not fairly represent the conditions at the upper end of le area, for there the population is extremely dense, especially at ardner. During the decade 1890–1900 there was a fair percentage increase in the towns drained by this river, although it was for the *ost part confined to the towns of Gardner, Athol, Orange, and Win*

chendon, while there was a decrease in the remaining places. Wa supplies have been established at the above-named places, wl sewerage systems have been laid at Orange and Gardner. Th facts make it patent that Millers River receives considerable pol tion, and, as the greatest population is near the headwaters, the ri is unfitted for several uses throughout its whole length.

NORMAL WATER IN MILLERS RIVER.

It appears from the Massachusetts map of normal chlorine that t normal for Millers River varies from 0.8 to 1.2 parts per million, av aging about 1. Reports of the analyses of normal water are not pl tiful for this drainage area, the only one appearing in the Massach setts reports is of the well at the waterworks at Winchendon. Tl and several others in which the amount of chlorine does not great exceed the normal are reproduced in the following table:

TABLE 42.—*Analyses of normal water in Millers River drainage area.*

[Parts per million.]

Location.	Color.	Nitrogen as—				Chlorine.	Residue on evaporation.	Hardness.	Number of analyses
		Ammonia.		Nitrites.	Nitrates.				
		Albuminoid.	Free.						
Well in Winchendon..	0.33	0.012	0.004	0.000	0.043	1.1	31.4	11	
Orange waterworks ..	1.6	.112	.010	.000	.019	1.8	30.6	6	
Athol waterworks....	6.9	.342	.067	.000	.049	1.3	38.1	6	
Gardner waterworks .	.7	.161	.014	.000	.055	3.3	30.3	10	(

[a] Covering eight years.

The characteristics of the waters represented in the foregoing ta are well shown. They are all acceptable for any of the ordin uses and retain all the values of natural waters. The first and o normal water in the list is a well water. That it is a typical w water is shown by the color, which is very faint, practically abse The low content of free and albuminoid ammonia is what might demanded in a well water, and the evidences of its condition are f ther borne out by the absence of nitrites.

The Athol and Orange waters are from impounding reservoirs, a therefore are largely made up of surface drainage. The analy show that oxidation had been rapid and that the character of water is acceptable. The chlorine is above the normal, not very m to be sure, but sufficient to denote that the drainage area of the re *voirs has a certain* population which contributes sewage to the natu *drainage, and* although its bad effects have long since been wa

away the traces still remain and neither water can be classed as normal.

The analysis of the Gardner water is instructive. It is apparently a water which has at some time been highly polluted, but which, through filtration, sedimentation, etc., has been reclaimed. The amount of chlorine, 3.3 parts per million (the normal for this country being 1.2) is unmistakable evidence of past pollution. In the previous pages mention has been made of waters which have been redeemed from contamination by means of artificial filters, but this is the clearest case noted in which the work has been done by natural conditions only.

Parts of the drainage basin of Millers River are thickly settled, which will account for the fact that none of the surface waters thus far analyzed are normal. The amount of chlorine found in a surface water bears a direct relation to the number of persons dwelling upon the land drained by that water. It follows, then, that while it may be impossible in a thickly settled country to secure normal water in large quantities, it is not necessarily impossible to so dispose of the wastes from the inhabitants that the resulting surface water may serve all purposes to which normal waters are applicable.

POLLUTION IN MILLERS RIVER.

The water of Millers River has been examined regularly by the Massachusetts State Board of Health at a point above Athol, where the pollution from Gardner and Winchendon may be detected, and again at a point below Orange, where the water contains the pollution from Gardner, Winchendon, Athol, and Orange. The analyses at these points are reported in Tables 43 and 44.

TABLE 43.—*Analyses of water from Millers River above Athol.*

[Parts per million.]

Date of collection.	Appearance.		Residue on evaporation.			Ammonia.				Chlorine.	Nitrogen as		Oxygen consumed.	Hardness.
	Turbidity.	Sediment.	Color.	Total.	Loss on ignition.	Free.	Albuminoid.				Nitrates.	Nitrites.		
							Total.	Dissolved.	Suspended.					
1900.														
July 17	Very slight.	Very slight.	6.1	36.0	15.0	0.072	.264	0.240	0.024	2.0	0.010	0.000	8.1	5
Aug. 21	Decided	Considerable.	7.8	51.0	21.0	.032	.480	.344	.136	1.2	.030	.004	10.3	11
Sept. 19	....do	....do	7.0	64.5	17.5	.020	.775	.268	.507	1.4	.100	.002	6.7	11
Oct. 16	Very slight.	Very slight.	8.7	64.5	24.0	.048	.300	.284	.016	1.9	.110	.000	12.5	18
Nov. 20	Slight	....do	7.2	53.0	17.0	.028	.360	.204	.156	1.9	.120	.000	10.9	14
Dec. 20	Very slight.	Considerable.	5.0	37.5	15.0	.018	.318 .416	.160	.158	1.2	.100	.000	7.5	16
Average			7.0	51.1	18.2	.036	.416	.250	.166	1.6	.078	.001	9.3	12

TABLE 44.—*Analyses of water from Millers River below Orange.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 24	Slight	5.9	0.292	0.064	0.002	0.010	2.8	35.0	5
August 22	Very slight	7.0	.292	.046	.001	.050	2.4	43.5	6
September 21	do	5.4	.240	.060	.001	.040	2.1	43.0	6
October 24	do	9.0	.376	.064	.002	.030	2.6	55.5	11
November 20	do	9.5	.284	.056	.001	.060	2.6	45.0	11
December 24	Decided	6.0	.260	.124	.000	.130	2.1	45.0	6
Average		7.1	.291	.069	.001	.053	2.4	44.5	7

DEERFIELD RIVER.

The Deerfield is the second largest tributary of the Connecticut. It rises in southern Vermont, crosses the Massachusetts State line, and, a few miles across, turns eastward and enters the Connecticut about 7 miles below the mouth of Millers River. The river has been little developed, and for the most of its length runs wild and free. There are many good and available power privileges, the slope is rapid, and the country is conveniently traversed by railroads, yet very few industries have been established in it. The elevation of the Deerfield at Readsboro, Vt., at the mouth of the West Branch, is 1,154 feet, while 42 miles below, at its mouth, its elevation is about 126 feet. There is practically no storage upon the drainage area in Massachusetts and very little in Vermont, therefore the flow is variable. In many places where power sites are otherwise excellent the valleys are too narrow for the location of mills. The river drains 656 square miles.

The total population of the basin is about 24,400, or approximately 37 per square mile. There is no important city within the watershed. Garfield, with a population of 7,927, is the largest place, but it is at the mouth of the Deerfield, and is also drained by the Connecticut itself. Shelburne and Colerain are next in size, with 1,508 and 1,749 inhabitants, respectively. Shelburne Falls is the only manufacturing town in the drainage area, although there are powers developed at Hoosac and Readsboro. There are no sewerage systems in the basin, the country is not highly fertile, and these facts, taken together with the sparse population, indicate clearly the character of the water.

Deerfield is, in effect, another river system which has been pre-
ed in practically its origin l condition, with all its normal resources
ffected.

ew analyses are available to show the character of the water of Deerfield. These are included in Table 45.

TABLE 45.—*Analyses of water from Deerfield River at various points.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Place of collection.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
None		0.005	0.024	0.000	0.130	....	28.0	..	Above Readsboro.
Very slight		.120	.020	.000	.020	.....	29.0	..	Monroe.
....do	3.7	.110	.004	.000	.120	0.5	28.5	5	Florida.
....do	.8	.085	.011	.000	.160	1.1	48.0	24	Colerain.
.....	.7	.054	.008	.000	.102	1.0	49.1	28	Leyden.
.....	3.2	.120	.008	.000	.097	1.0	36.0	17	Above Shelburne Falls.

omment on the results set down in Table 45 seems unnecessary. e waters there represented are practically normal, the evidence of age pollution being very faint and the polluting substances having n practically all reduced to inorganic matter.

CHICOPEE RIVER.

The Chicopee is formed at Three Rivers by the union of the Quaboag, are, and Swift rivers. The Quaboag is the most southerly, and ains 210 square miles; the Ware drains 214 square miles, while the sin of the Swift covers 219 square miles. The total discharge aver-s 669 cubic feet per second.

Drainage area.—The drainage area of the Chicopee (see fig. 9) is ger than that of any other tributary of the Connecticut, comprising square miles in central and southern Massachusetts, and occupy-large portions of Worcester, Franklin, Hampshire, and Hampden nties. The country is fairly prosperous, and has constantly reased in population since the middle of the last century. During ent decades this increase has been confined to the cities and large lages, the rural population having decreased considerably. The untry is very accessible, being traversed by excellent railroad sys-ns, which have been of value to the power facilities of the river. is hilly, with open valleys, the soil being principally bed gravel ssed by ledges of red sandstone, which form numerous falls in the ers that flow through the district. The slope of the rivers through-t the whole system averages 15 feet per mile, but the maximum for rtain sections is far greater than this.

Pondage.—There are in the basin many natural reservoirs, which serve to maintain comparatively steady flow in the streams. There

FIG. 9.—Chicopee River drainage basin.

is also considerable swamp land, especially along the Quaboag River, which materially assists in the maintenance of a uniform rate of flow.

TABLE 46.—*Principal ponds in basin of Chicopee River.*

Locality.	Name of pond.	Area.	Tributary to what stream.
		Acres.	
Prescott	On West Branch of Swift River.	154	West Branch of Swift River.
New Salem	Thompsons Pond	235	Middle Branch of Swift River.
Greenwich	Curtis Pond	155	Do.
Do	Luce Pond	124	Do.
Do	West Pond	94	Do.
Petersham	Reservoir (no name given)	175	Do.
Dana	Neeseponsett Pond	118	Do.

BLE 46.—*Principal ponds in basin of Chicopee River*—Continued.

ality.	Name of pond.	Area.	Tributary to what stream.
		Acres.	
h	Davis Pond	100	East Branch of Swift River.
	Pottapang Pond	160	Do.
n	Phillipston Pond	202	Burn Shirt River (to Ware).
	Pond northeast of above	130	Do.
ston	Reservoir near Westminster.	90	Ware River.
	Moosehorn Pond	160	Do.
	Asuyconie Pond	238	Do.
r	Muddy Pond	202	Do.
	Reservoir (no name given)	200	Do.
	Pond west of center	135	Do.
	Long Pond	160	Do.
	Demon Pond	138	Do.
intree	Two ponds near center	94 75	Quaboag River.
	Browning Pond	140	Do.
okfield	Wickaboag Pond	323	Do.
ookfield	Brooks Pond	178	Do.
	Furnace Pond	305	Do.
d	Podunk Pond	508	Do.
	South Pond	340	Do.
	Cranberry Meadow Pond	107	Do.
	Total area of 28 ponds.	5,040	

r *values.*—The Tenth Census Report on Water Power contains llent description of the power utilized on the Chicopee. It hat the main river is an extremely valuable one, and has prominence by reason of the extensive cotton and other manu- g industries established along its course. The available fall river has been practically all utilized. Of the three main s the Quaboag is the most valuable for power because of its tained flow, the value of the Ware and the Swift rivers fol- losely in the order named.

acter of water in the Chicopee Basin.—The following towns ated partly or wholly within the Chicopee Basin: Chicopee, , Belchertown, Palmer, Monson, Wales, Brimfield, Warren, eld, West Brookfield, North Brookfield, Spencer, Paxton, New ee, Ware, Enfield, Hardwick, Oakham, Greenwich, Prescott,

Pelham, Shutesbury, Dana, Barre, New Salem, Wendell, Petersham, Phillipston, Templeton, Hubbardston, Rutland, Wilbraham, and Springfield.

The population in the drainage area is about 90,000, or 127 per square mile.

WARE RIVER.

The watershed of Ware River adjoins that of the Nashua. It has an elevation in the towns of Oakham and Barre of about 645 feet above high tide. The population is small and the pollution is therefore not objectionable, and from a sanitary point of view the stream is an excellent source of water supply. The area has been considered a favorable one by the Metropolitan Water Board of Massachusetts as a part of the natural gathering ground for the future supply of Boston and the vicinity. It forms a link in the chain of gathering grounds in central Massachusetts, which will at some day in the future, when the demands require it, be connected with the Nashua and the waters carried through the long aqueducts to the distribution stations in the vicinity of Boston.

Analyses have been made periodically by the Massachusetts State Board of Health of the water in Ware River at Coldbrook station, in the town of Barre. The average results for each year are included in Table 47.

TABLE 47.—*Analyses of water from Ware River at Coldbrook station at Barre.*

[Parts per million.]

Year.	Color.	Nitrogen as				Chlorine.	Total r...	Hardness.	Number of analyses made.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1894	7.4	0.178	0.005	0.000	0.023	1.4	35.5	8	12
1895	7.8	.219	.014	.000	.051	1.7	39.6	9	12
1896	7.2	.198	.003	.000	.038	1.1	33.6	8	6
1897	8.3	.193	.010	.000	.032	1.4	36.0	7	12
1898	7.6	.196	.011	.000	.027	1.4	35.1	7	12
1899	5.0	.184	.010	.000	.032	1.4	33.8	4	12
1900	6.2	.227	.025	.000	.014	1.4	36.6	5	7

The color of the water is fairly high, due, no doubt, to a considerable extent of swamp land. The amount and condition of the organic matter is not particularly suggestive, save that the free and albuminoid ammonia in 1900 is higher than in previous years, showing additional organic pollution, the source of which is not apparent. The normal chlorine for this region is from 1.1 to 1.2 parts per million, so

at the average of 1.4 parts in the table above set forth shows a slight wage contamination.

In the basin of Upper Ware River is Musquapog Lake, the source the water supply of Rutland. The following analyses were made the water from this lake in the year 1900:

TABLE 48.—*Analyses of water from Musquapog Lake.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
Jan. 31	Very slight	0.2	0.118	0.098	0.001	0.010	1.6	17.5	5
Aug. 14	do	.1	.188	.010	.000	.000	1.4	17.0	2
Sept. 26	do	.2	.130	.044	.000	.020	1.4	21.0	3
Dec. 20	do	.2	.218	.070	.001	.030	2.8	29.0	5

The water supply of Barre is collected in a reservoir within the town, the water flowing from several springs in the vicinity and from the surface of the ground for a considerable area above. Analyses of this water, made in 1898, are reported as follows:

TABLE 49.—*Analyses of water from the reservoir of the Barre Water Company.*

[Parts per million.]

Date.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1898.									
Jan. 11	Decided	1.5	0.096	0.002	0.000	0.000	1.4	25.0	10
Apr. 12	do	1.1	.272	.018	.002	.002	1.5	19.0	8
July 5	Slight	1.1	.330	.042	.001	.001	1.3	25.0	5
Oct. 5	do	1.0	.536	.156	.000	.020	1.4	25.0	8
Average		1.2	.308	.054	.001	.032	1.4	23.5	8

Ware River, after flowing by the town of Barre, which has a population of over 8,000, plainly shows the effects of pollution. A large number of the houses and some of the factories of Ware empty their wastes directly into the river. Analyses of samples of water taken from the river below the town, made by the State Board of Health, in the year 1900, are given in table 50. When these are compared with those made of the water collected at Cold Brook Station the change is clearly illustrated.

TABLE 50.—*Analyses of water from the Ware River below Ware.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	4.1	0.312	0.060	0.008	0.000	2.1	46.5	10
August 22	Decided	3.7	.324	.032	.002	.040	2.2	45.0	8
September 20	do	3.4	.404	.076	.003	.020	3.3	52.0	11
October 16	Very slight	7.3	.288	.052	.002	.040	2.4	54.0	11
November 19	Decided	7.0	.275	.110	.001	.050	2.5	49.0	14
December 19	do	5.0	.288	.132	.002	.120	2.5	51.0	11
Average		5.1	.315	.077	.003	.045	2.5	49.6	11

Not far below the point where these samples were collected Ware River joins the Swift and the Quaboag. The analyses in table 49 therefore represent the character of the water contributed by the Ware River to the Chicopee system.

SWIFT RIVER.

Swift River is the westernmost of the three main branches of the Chicopee. Below the town of Enfield it has an elevation of 376 feet above tide. It drains an area of 185.7 square miles, which has a population of 128 per square mile. This area, like that of the Ware, has been considerd as a source of water supply by the Metropolitan Water Board. The water is of excellent quality and has little color. The following analyses have been made by the State Board of Health of Massachusets.

TABLE 51.—*Analyses of water from Swift River at designated points.*

EAST BRANCH IN GREENWICH.

[Parts per million.]

ste.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of samples analyzed.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
.....	4.7	0.146	0.011	0.000	0.015	1.5	31.0	8	2
MIDDLE BRANCH IN GREENWICH.									
.....	3.8	0.115	0.012	0.000	0.000	1.3	31.5	9	2
BARRETTS JUNCTION.									
.....	3.2	0.167	0.012	0.000	0.040	1.6	33.3	10	3
TOWN OF ENFIELD.									
.....	0.4	0.030	0.000	0.000	0.058	1.1	25.8	7	6

QUABOAG RIVER.

Quaboag is the southernmost of the three main branches of the pee. It drains the whole area of the towns of Monson, Brimfield, Braintree, Oakham, Spencer, and Paxton. The population per e mile is 125, which is considerably larger than in the Ware and basins. The character of the unpolluted water in the drainage of the Quaboag is well shown in the following series of analyses:

TABLE 52.—*Analyses of unpolluted water in Quaboag Basin.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
oir, Monson	1.1	0.355	0.030	0.004	0.105	1.7	34.5	....
Pond, Spencer	.3	.136	.007	.....	.059	1.4	26.9	....
ell, Monson	.1	.011	.002	.000	.095	1.2	33.3	10
)	.0	.006	.001	.000	.078	1.3	32.2	7
; North Brookfield.....	.0	.008	.010	.000	.245	1.4	37.0	9
Pond, North Brookfield ..	5.3	.308	.145	.002	.050	1.2	31.5	4
Pond, Spencer	.3	.148	.018	.000	.090	1.6	22.2	5

The settlements along the Quaboag which contribute a considerable amount of matter to the river above the town of Palmer are Spencer, Brookfield, North Brookfield, Warren, and Monson. After the water has passed all these points it is in the condition indicated in the following table:

TABLE 53.—*Analyses of water from Quaboag River above Palmer.*

[Parts per million.]

Date of collection.	Turbidity.	Color	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Very slight	4.4	0.196	0.040	0.001	0.010	1.9	41.0	11
August 21	Slight	5.1	.236	.032	.001	.010	2.5	47.0	10
September 19	Very slight	3.5	.208	.028	.001	.030	2.8	42.5	13
October 29	Slight	4.4	.248	.048	.002	.040	3.1	45.0	14
November 20	do	4.3	.216	.036	.000	.110	2.9	44.5	17
December 18	do	4.5	.198	.010	.003	.100	2.5	42.5	11
Average		4.4	.217	.032	.001	.050	2.6	37.7	13

After receiving considerable sewage from Palmer, the river below is not apparently in a worse condition from the standpoint of organic content than it was above that town. This fact is shown by the following analyses:

TABLE 54.—*Analyses of the water of the Quaboag River below Palmer.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Very slight	4.1	0.180	0.040	0.001	0.030	1.8	41.0	13
August 21	Slight	5.0	.246	.044	.001	.050	2.4	51.5	8
September 19	Very slight	3.1	.198	.008	.001	.050	3.0	44.0	13
October 29	Slight	4.0	.248	.048	.002	.040	3.1	47.0	10
November 20	Decided	3.7	.216	.048	.000	.140	2.9	44.5	16
December 18	Slight	4.1	.190	.008	.003	.120	2.5	43.5	11
Average		4.0	.213	.033	.001	.072	2.6	45.2	12

A comparison of the two tables shown above illustrates in a fairly clear way a point made at the beginning of this discussion, which is, that analysis of water is not always effectual in showing its condition from the standpoint of general healthfulness. It is plain that the water of Quaboag River can not be as safe for public use after it has passed the town of Palmer as it was above this point. The amount of pollution from Palmer is rather extensive, but it is not apparent in the analysis of the water. The reason for this is probably that the amount of pollution is not sufficient to appreciably change the quantity of organic matter contained in so large a flow as that of the Quaboag, yet it is undoubtedly true that if the germs of any water-borne disease, such as typhoid fever, were brought into the river from Palmer, the use of the water below Palmer would be extremely dangerous, even though the analysis would seem to show that, from the standpoint of organic content, the river had not changed.

From the confluence of the Swift, Ware, and Quaboag rivers the Chicopee runs almost due west, past the municipalities of Ludlow, Wilbraham, Chicopee, and Springfield. The first village below Three Rivers is Ludlow, from which there is considerable sewage emptying into the Chicopee. The average of six analyses of the water below Ludlow made in the year 1900 is reported as follows:

TABLE 55.—*Analyses of water from the Chicopee River below Ludlow.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900	3.8	0.240	0.042	0.012	0.098	2.8	46.0	12

After receiving sewage from Indian Orchard, Chicopee Falls, and a part of Chicopee the river enters the Connecticut. No recent analyses of the water of the river at a point below that are available.

WESTFIELD RIVER.

Drainage basin.—Westfield River is a branch of the Connecticut which enters the latter from the west at a point opposite Springfield, Mass. (See fig. 10.) It has a drainage area of about 515 square miles, all of which is situated within the State of Massachusetts. Above a point 16 miles from the mouth of the river the country is extremely hilly, and in the upper districts it is even mountainous. The maximum fall from source to mouth is, where measured via the West Branch, about 1,162 feet, or an average of 32.5 feet per mile. In the

upper part of the river, however, the fall averages usually 70 feet per mile.

The rainfall on the watershed finds its way over the steep slopes rapidly and the flow of the river fluctuates in consequence. This flood flow is not steadied by any considerable storage within the basin, for there are few natural ponds or lakes, and little or nothing has

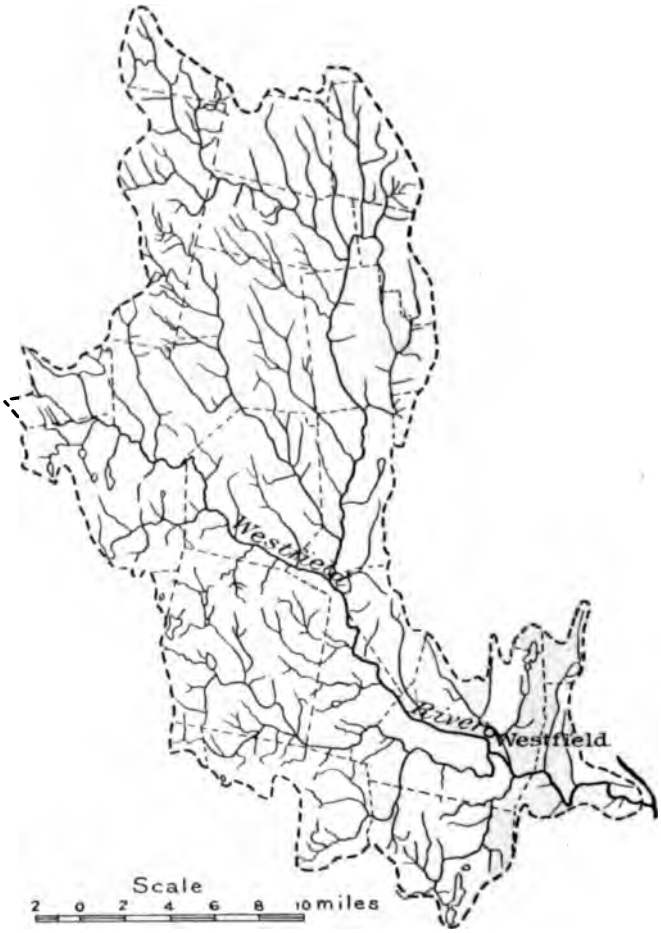


FIG. 10.—Westfield River drainage basin.

been done to impound the waters. Gen. Theodore G. Ellis, Chief of Engineers, U. S. Army, has given the average flow of the river as 500 cubic feet per second, but this is believed by Professor Porter to be too large.

Population.—The development of the drainage area of the Westfield has been slow and the growth of population slower. In a great majority of the towns there has been a decrease in the number of

nhabitants within the decade 1890–1900. A large part of the basin as no railroad facilities whatever, and there has been no need of any. n short, the country has not shared the industrial and commercial dvancement which has been made by the greater part of the surounding sections. In the lower parts of the area, notably in Westield, there has been an increase in population amounting to 25 per ent in the last decade. Exclusive of this town and West Springfield, he most populous part of which drains into the Connecticut, the lrainage area has a population of about 23 per square mile.

Character of water.—On account of the small population the character of the water is excellent, and the river above the town of Westfield may be considered practically unpolluted. The following expressive statement is found in the report of the State Board of Health of Massachusetts for 1890:

> Analyses of the water of the Westfield River have not been made regularly, because it was polluted so little during the time covered by these investigations (1887–1889) that it seemed unnecessary.

As above noted, conditions in the river have not changed, except in the lower end; therefore the passage quoted applies at the present time. The construction of a sewerage system at Westfield and the location of its outlet in the river has made it necessary to examine the waters above and below the outlet in order to show the effect upon the river. In the investigation of water supplies for different towns in the district, several analyses of water in the drainage basin were made.

TABLE 56.—*Analyses of normal water of the Westfield River system.*

[Parts per million.]

Point of taking sample.	Turbidity.	Color.	Nitrogen as-				Chlorine.	Total residue.	Hardness.	Number of samples analyzed.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Chester	None	0.9	0.068	0.004	0.001	0.120	1.0	32.5	11	1
Huntington (Middle Branch).	do	.9	.063	.004	.000	.043	.9	32.1	15	14
Huntington (East Branch)		1.4	.087	.005	.000	.053	1.0	33.2	14	14
Russell	Very slight.	1.2	.078	.010	.000	.070	.7	32	1	1
Granville		1.3	.071	.013	.000	.027	1.2	26.7	4	14

The above analyses represent the characteristics of water, which may fairly be called normal, obtained from different parts of the drainage area. It will be seen that there is very little difference in the color of the various samples and that the residue and the albuminoid ammonia are remarkably uniform. The Granville sample shows higher free ammonia and chlorine than the preceding ones, which for the moment looks threatening, but it will be seen that the actual departure from the normal is wholly within the limits of error, and if there is any pollution in the Granville sample it is not sufficient to produce significant changes, so that the water from nearly the whole Westfield area is of practically normal character. The basin remains in a condition in which may be realized all the resources which its streams can provide. The public demand for drinking water may be met at almost any point, and there is no blemish on the ice fields. The manufacturer may use the water with impunity, for it is not changed sufficiently to injure his products. That this district, lying between the metropolitan area of New York and the prosperous country of central Massachusetts, should remain throughout its greater part in normal condition is worthy of remark.

We will now trace the changes that take place in the water of Westfield River after it passes the town of Westfield, with its population of 12,310.

TABLE 57.—*Analyses of water from Westfield River above and below Westfield.*

[Parts per million.]

Point of taking sample.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of samples examined.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Above Westfield	2.2	0.135	0.013	0.000	0.035	1.3	42.6	19	15
Below Westfield	2.0	.296	.128	.004	.069	2.3	49.9	23	11

The analyses in the table above are of peculiar interest, as they show the effect of a single sewerage system on a pure stream. From what has gone before it will be remembered that Westfield River receives practically no significant pollution until it reaches the city of Westfield, but in passing the city it is changed from a normal river to a polluted one. Let us consider the significance of the determinations in Table 57. The average of the samples taken below the city shows a great increase in the amount of polluting material. Free ammonia, nitrites, and chlorine, the special indicators of the presence of sewage pollution, are all present in increased quantities, while the

nounts of nitrates and albuminoid ammonia assume a proper relation
the whole.

HOCKANUM RIVER.

Drainage area.—On the boundary between the towns of Tolland nd Ellington, Conn., there is a lake, the level of which has been so ised by a stone embankment 35 feet high that it has an expanse of 0 acres. Its drainage area is 15.4 square miles, but in addition to e surface water which accumulates from this territory, it is largely d by hidden springs. This lake, called Shenipsit, is the source f Hockanum River, which flows thence in a southwesterly course, mptying into Connecticut River opposite Hartford. The Hockanum s principally important by reason of the power developed along ts course, for although it is less than 20 miles long it furnishes ,957 horsepower.

Flow.—According to the measurements of General Ellis, Chief of Engineers of the U. S. Army, the flow of the river averaged 132 cubic eet per second, its maximum flow being 6,167 second-feet. The flow s peculiar by reason of the fact that about 2,000,000 cubic feet a day are allowed to run from Shenipsit Lake during working hours while no water is permitted to flow at night or on holidays.

There are several factories on the banks of the river, most of them works for the manufacture of textile fabrics and paper. Just below Shenipsit is Rockville, where 1,400 horsepower are developed.

Character of water.—Shenipsit Lake drains an area which is sparsely settled, and its water is therefore practically normal and of excellent quality. It is used as a supply for the city of Rockville and has been analyzed by the State Board of Health of Connecticut.

TABLE 58.—*Analyses of water of Shenipsit Lake.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Samples averaged.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1890–91	0.1	0.194	0.027	0.001	0.05	1.66	31.3	7	11
1900	.3	.107	.021	.000	.08	1.42	31.2	5	12

Taylor's reservoir, on the south branch of the Hockanum, is another body of normal water. It is used as a source of supply for South Manchester, Conn. Analyses made by the Connecticut State Board of Health in the year 1900 are reported as follows:

TABLE 59.—*Analyses of water from Taylor's reservoir, Manchester, Conn.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
Jan. 24	Very slight	0.4	0.130	0.028	0.001	0.10	1.7	34.5	3
Mar. 15	Clear	.1	.102	.044	.001	.05	1.5	32.0	5
May 10	do	.2	.110	.038	.002	.05	1.5	34.0	5
July 3	do	.1	.068	.022	.001	.02	1.7	35.0	3
Sept. 13	do	.1	.108	.018	.000	.03	1.6	36.5	4
Nov. 7	do	.1	.112	.112	.000	.08	2.1	37.5	3
Average		.2	.105	.025	.001	.05	1.68	34.9	4

Pollution.—The Board of Health of the State of Connecticut is investigating the character of the water in Hockanum River, samples being collected at three available points, viz, Windermere, North Manchester, and Burnside.

This work was done during the years 1895, 1896, and 1900, the samples being collected monthly, from May to October in each year. They indicate extensive pollution of this stream, but since its principal resource is water power, the damage done is not significant. The character of the water will doubtless be better in the future, by reason of the installation of a sewage purification plant in the village of South Manchester.

TABLE 60.—*Analyses of water from Hockanum River at Windermere, North Manchester, and Burnside.*

[Parts per million.]

WINDERMERE.

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	0.5	1.470	0.071	0.017	0.160	4.85	138.9	13
1896	.5	.913	.070	.008	.180	4.49	98.6	....
1900	.4	.910	.073	.010	.250	3.38	71.9	....

TABLE 60.—*Analyses of water from Hockanum River, etc.*—Continued.

NORTH MANCHESTER.

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	0.5	1.096	0.124	0.008	0.110	3.87	82.1	15
1896	.5	.762	.063	.009	.160	4.45	78.3	....
1900	.3	.752	.167	.022	.240	3.95	75.4	....
BURNSIDE.								
1895	0.4	0.802	0.172	0.025	0.100	6.03	98.6	37
1896	.4	1.156	.194	.023	.140	5.61	81.4	....
1900	.4	.722	.183	.025	.160	4.65	80.7	....

PARK RIVER.

Park River is a small stream entering the Connecticut from the west. In its drainage area are the cities of New Britain and a part of Hartford. The flow is small, and, as there is a large amount of sewage brought into the river, it is probably the foulest stream in the State of Connecticut. The report of the State Board of Health made in 1895 contains the following comments:

The result of the analyses at New Britain indicate that at times during the summer the water of the stream contained as much as four-fifths of its volume of sewage. Between New Britain and section No. 2, at Newington Junction, there is practically no sewage addition. From the respective areas of the watersheds the volume of the stream at Newington should be about five times what it is at New Britain, but that the dilution must be less than this is at once apparent when it is considered that the greater part of the flow at station No. 1 is sewage and comes from other watersheds, from which the water supply is drawn. A better means of measuring dilution is by the comparison of the amounts of chlorine at the two stations, for this constituent is not removed from the stream after once having been introduced, either by precipitation or by the acts of living organisms. Since the normal chlorine of the region is about 2, there would be two parts of chlorine per million in the water of dilution added between New Britain and Newington, and, since the average amount of chlorine at the two stations is 33.1 and 15.1, respectively, it is easy to calculate that the dilution at Newington Junction is 2.4.

The average amount of nitrogen of free ammonia at New Britain was 3.04. A dilution to the extent indicated above would reduce the nitrogen of free ammonia at Newington Junction to 1.25, but the amount actually found was 2.35, a very considerable increase. This, of course, was due to putrefactive change occurring during the flow of 3¼ miles. That the changes occurring during this course were putrefactive and not oxidizing in character is shown, not alone by the increase of free

ammonia, but also by the figures for nitrites and nitrates, which show no increase, but, on the contrary, a slight relative diminution.

A similar calculation for the nitrogen of organic matter in suspension shows that there was a decrease of about 30 per cent, due, doubtless, chiefly to sedimentation. The decrease of nitrogen of organic matter in solution was somewhat more than the increase of nitrogen of free ammonia. In flowing through the course of 3¼ miles, therefore, there was some purification by sedimentation, but apparently none by oxidation, and very little by precipitation and other means. The improvement in the stream at the lower point is consequently due almost wholly to dilution with clean water from the watershed between the two stations.

Below Newington Junction there is a large increase in the flow, the relative watersheds being as 1 to 5.6. There is little direct contamination until the sewers of Hartford are reached. There are several of these in the last mile above station No. 3 in Hartford. The contamination effected by their discharge is so great that, although there is a dilution of nearly sixfold, the water in the stream at this point is about in the same condition as at Newington Junction; indeed, in respect to the organic matter the contamination is greater in Hartford.

Analyses of the water of this river were made by the Connecticut State Board of Health in the years 1895, 1897, and 1899 at New Britain, Newington, and Hartford, and the average of the results for each year are set forth in Table 61.

TABLE 61.—*Analyses of water from Pipers Brook and Park River.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Samples analyzed.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
NEW BRITAIN.								
1895	0.5	6.71	3.04	0.396	1.15	33.0	290.9	6
1897	.4	7.08	3.41	.217	1.24	26.2	271.6	6
NEWINGTON.								
1895	0.7	1.57	2.33	0.064	0.37	15.1	160.8	6
1897	.6	2.64	2.07	.064	.28	13.2	150.0	6
1899	.8	2.52	4.42	.024	.09	16.9	155.6	6
HARTFORD.								
1895	0.6	3.71	2.27	0.035	0.19	13.1	151.9	6
1897	.5	5.21	2.17	.158	.23	17.0	172.2	6
1899	.4	2.22	1.22	.208	.20	9.2	138.3	6

The pollution of Pipers Brook by the city of New Britain led to a lawsuit against the city, the final decision in which was rendered by the supreme court of errors of the first judicial district of the State of Connecticut, during the May term, at Hartford, in 1897. The suit was brought for injunction and damages before the superior court in Hartford County by Patrick Nolan, the jury giving verdict and judgment for plaintiff in $2,000 damages. The plaintiff owned a farm near Newington on Pipers Brook below the city of New Britain, upon which were dwelling houses and other buildings. The complainant stated that from October 1, 1887, to the date of complaint, the city had dumped acid, sewage, and other deleterious matter into the river and deprived him of the use of water for stock and for domestic purposes, and he had been put to a large expense thereby, his lands being injured for pasturage, his milk business having been injuriously affected, and the ice crop upon the stream having been made valueless.

The following extracts are taken from the opinion rendered by the court, the same having been handed down by Chief Justice Andrews (69 Conn., 668):

The use of Piper's Brook which the complainant charges that the defendant has made, unless there is a lawful warrant therefor, causes a public nuisance. Anything not warranted by law, which annoys or disturbs one in the use of his property, rendering its ordinary use or occupation physically uncomfortable to him, is a nuisance. (Baltimore and Ohio Railroad *v.* Fifth Baptist Church, 108 U. S., 317.) * * * The test is not the number of persons annoyed, but the possibility of annoyance to the public by the invasion of its rights. * * * (Westcott *v.* Middleton, 43 N. J. Eq., 478.) * * * That it would be a public nuisance to render the water of a stream so impure that it could not be used for domestic purposes, or for the watering of cattle, and so that it gave off noxious and unhealthy odors, is hardly open to question (Chapman *v.* Rochester, 110 N. Y., 273), for the reason that these causes would injuriously affect every riparian owner along the whole length of the stream and every person who lived near it. If a municipal corporation, in the absence of a legal right so to do, causes sewage to pollute a watercourse, to the use of which a lower owner, through whose premises the watercourse flows, is entitled, it is guilty of a nuisance for which damages may be recovered. * * * * * * The second defense depends on the act of the legislature of 1872, mentioned in the statement of the case.

* * * The said act authorizes and points out the steps to be taken in order to complete within said city a valuable public improvement, to be paid for by that species of taxation known as the assessment of damages and benefits. It empowers the common council, "whenever in their opinion the public health or sewerage shall require such action, to take, occupy, and appropriate, in such manner as they shall, from time to time, deem expedient, any stream or part of a stream, natural or artificial, running in or through said city, and to straighten, deepen, or lower the same, or lower or remove any or all walls, dams, or other obstructions to the free and healthy flow of such stream or part of a stream, or to enlarge or cause to be enlarged or lowered, any or all culverts which at any season of the year cause the accumulation of stagnant water or interrupt in any manner the free and healthy flow of any part of such stream." This is all of the act which grants power *to the defendant to interfere* with Piper's Brook. * * *

If it had been the intent of the legislature, by the act of 1872, to authorize the

common council of the city of New Britain to take or to affect any lands outside of the city limits, it is certain that there would have been in the act some provision for the ascertainment of damages to be paid to the landowner. The right of the plaintiff to have the water of Piper's Brook flow through his land as it has been accustomed to flow [i. e., pure and uncontaminated] "is not an easement or appurtenance, but it is inseparably annexed to the soil." (Wadsworth v. Tillotson, 15 Conn., 366, 373.) To deprive the plaintiff of that part of his soil for the purposes named in that act would be the taking of private property for public use, and the plaintiff would be entitled to have just compensation.

The procedure of the trial court was sustained and the award affirmed.

FARMINGTON RIVER.

Farmington River is an important stream which rises in Berkshire County, Mass., and, after a peculiar and erratic course, enters Connecticut River from the west about 5 miles above the city of Hartford. It is a notable power stream, having a fall of about 1,200 feet, a mean discharge at the mouth of the river of about 944 cubic feet per second, and a maximum discharge of nearly 25,000.

The surface of the Farmington River Basin is hilly, the uplands are well wooded, and the valleys extensively cleared for farming purposes. There are many ponds in the basin, and these, with the surface waters, maintain a fairly steady flow during the dry seasons. Indeed, it has been claimed that the development of water storage on this river has practically reached its height.

No examinations of water of the Farmington River are available. Although there are a number of thriving manufacturing villages along its course, there are no important towns in the basin; therefore pollution can not be sufficiently extensive to greatly damage the river.

CONNECTICUT RIVER.

Analyses of the water of Connecticut River at Northfield Farms, in the northern part of Massachusetts, just below the State line, show that the pollution which enters from the States of Vermont and New Hampshire has very little effect on the apparent composition of the water. Indeed, such is the dilution of the sewage poured into the river north of the Massachusetts line that the chlorine in the water at Northfield is nearly normal. In the Connecticut Valley in New Hampshire and Vermont there are only a few important towns, and these are probably not completely sewered, if at all. Brattleboro and Bellows Falls in Vermont, with populations of 5,297 and 4,377, respectively, are the only places in that State from which there is likely to arise any appreciable pollution. In New Hampshire, the city of Keene drains into the Connecticut by way of the Ashuelot, and the town of Claremont is situated directly upon the river. These places have *populations of* 9,165 and 6,498, respectively.

TABLE 62.—*Analyses of water from Connecticut River at Northfield Farms.*

[Parts per million.]

ate of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
ly 18	Slight	2.8	0.156	0.012	0.001	0.000	0.6	60.5	30
ugust 20	Very slight	3.0	.142	.006	.003	.040	.8	60.5	33
ptember 17	do	2.4	.114	.006	.000	.010	1.1	71.0	38
tober 15	do	8.3	.270	.045	.000	.050	.8	62.5	22
ovember 19	Slight	6.8	.270	.044	.001	.050	1.0	57.5	21
cember 17	Very slight	2.4	.148	.024	.006	.190	1.1	60.5	30
Average		4.3	.183	.023	.002	.057	.9	62.1	29

The available analyses of the river's water next below Northfield arms were made at Turners Falls, in the town of Montague, from 87 to 1889. Although, under ordinary circumstances, a series of nalyses made at such an early date would not be applicable to the resent conditions, the changes in the population above this point ave not been sufficient to materially alter the condition of the river. he average of 21 analyses is set forth in Table 63.

ABLE 63.—*Average of twenty-one analyses of water from Connecticut River at Turners Falls.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as-				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
light	3.0	0.140	0.025	0.003	0.123	1.0	63.8

The report of the Massachusetts State Board of Health for 1899 ives a significant analysis of the water of the Connecticut River pposite Northampton as follows:

TABLE 64.—*Analysis of water from Connecticut River at Northampton.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
Very slight	3.0	0.232	0.018	0.001	0.030	0.9	57.5	28

Continuing downstream we find that the next available analyses are those made by the State Board of Health of water taken from Connecticut River at a point below Springfield. Here are the first prominent indications of pollution shown by analytical methods. Above this point there are Chicopee, Westfield, and Millers rivers, which are, as has been already stated, in a polluted condition. On the main river there are the cities of Northampton, Springfield, and Holyoke, as well as smaller towns, all of which contribute a large measure of pollution. It is not surprising then, that by the time the river reaches this point below Springfield it should betray by chemical analyses the abuse which it has suffered.

TABLE 65.—*Analysis of water from Connecticut River below Springfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Very slight	2.5	0.184	0.112	0.002	0.010	1.7	61.0	34
August 18	Slight	2.4	.148	.112	.002	.020	1.6	61.5	34
September 18	Decided	2.9	.280	.156	.004	.040	2.9	78.5	36
October 18	Very slight	7.1	.268	.064	.002	.020	1.7	66.0	25
November 21	Decided	7.2	.368	.048	.002	.080	2.0	65.0	27
December 29	Slight	2.6	.152	.006	.001	.090	1.8	49.0	25
Average		4.1	.233	.083	.002	.043	1.9	63.5	30

Crossing over into the State of Connecticut, the river receives other and extensive pollution. The Farmington, Hockanum, Salmon, and other tributaries have already been discussed. On the main river are Hartford and Middletown, as well as numerous other smaller centers, which materially increase the amount of pollution. In the years 1890, 1893, 1894, and 1899, the State Board of Health of Connecticut made examinations of the water of the river at three points, viz: Warehouse Point, Rocky Hill, and Goodspeed Landing. Analyses made at these points are well adapted to show the effects of the contribution by various towns of new contamination to the already polluted river.

).—Analyses of water from Connecticut River at Warehouse Point, Rocky Hill, and Goodspeed Landing.

[Parts per million.]

WAREHOUSE POINT.

ar.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
.....	3	0.126	0.034	0.002	0.12	1.23	44.2	23
.....	3	.116	.086	"much"	.20	1.85	66.5	....
.....	3	.192	.064	.005	.06	2.58	76.5	44
.....	2	.130	.048	.002	.15	2.70	77.5	30

ROCKY HILL.

.....	3	0.135	0.033	0.002	0.11	1.28	44.6	25
.....	3	.112	.054	.010	.10	1.75	66.5	....
.....	3	.156	.102	.006	.30	3.50	73.5	48
.....	3	.164	.068	.008	.18	2.70	73.5	32

GOODSPEED LANDING.

.....	3	0.130	0.036	0.001	0.13	1.36	45.0	25
.....	3	.110	.044	.005	.08	1.81	65.5	....
.....	2	.182	.064	.004	.08	3.04	73.0	44
.....	3	.244	.066	.008	.20	3.20	73.0	32

is little to add concerning the Connecticut River and its
to the various interests which have claims upon it. There
son why this stream could not be kept in a condition that
e acceptable to all concerned. Under the present condi-
wever, much of its value is lost. The river comes down to
achusetts line practically uninjured, but in its course through
usetts it is robbed of its values as a source of water supply
ice. Under the present policy of the State authorities the
n of the river is not likely to grow worse, but, on the contrary,
loubt be improved, so that we can look forward with confi-
the removal of the dangerous wastes which are now poured
Connecticut system in Massachusetts. In Connecticut the
s great values as a source of power, as a means of navigation,
park nucleus, but the remainder of its normal values have
troyed.

HOUSATONIC RIVER.

NATURAL RESOURCES.

Course.—The Housatonic is an important stream flowing through the extreme southwestern part of New England. It has its origin in the central part of Berkshire County, Mass., being formed by the confluence of East and West branches, which unite at Pittsfield. From Pittsfield it flows southward in a somewhat tortuous course, passing into Connecticut through Litchfield County, and still farther south forming the boundary between New Haven and Fairfield counties, finally emptying into Long Island Sound near Bridgeport. (See fig. 11.)

Drainage basin.—The area drained by Housatonic River comprises 1,933 square miles, of which 503 are in Massachusetts. The river in its winding course traverses about 125 miles. The East Branch, which has a drainage area of 70 square miles, rises not far from Pittsfield, and flows by an extremely circuitous route through the manufacturing settlements of Hinsdale and Dalton, finally joining West Branch south of Pittsfield. The West Branch is formed by the overflow of Onota and Pontoosuc lakes, in Pittsfield, and flows in a southerly direction, draining an area of 59 square miles. One of the principal branches of West Branch is Southwest Branch, which rises in Richmond Lake and joins West Branch a short distance above its confluence with East Branch.

Fall.—The fall of the river between Pittsfield and Long Island Sound amounts to about 1,000 feet. It is distributed along gravelly shoals, with intervening stretches of quiet water. There are falls at New Milford, Bulls Bridge, and Falls Village.

TABLE 67.—*Table showing fall in Housatonic River.*

Locality.	Distance above mouth.	Elevation above mouth.	Fall between points.	Distance between points.	Average fall per mile between points.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*
Pittsfield, Mass	123	983			
Ashley Falls, Mass	81¼	705	361	50.5	7.15
Falls Village, Conn	72½	622			
1.8 miles above Cornwall Bridge	64	457	165	8.5	19.41
Mouth of Shepaug River	29½	105	352	43.5	10.90
Birmingham	11		105	18.5	5.68

The drainage area is hilly and even mountainous, the uplands are fairly well wooded, and the valleys are wide, with alluvial meadows. The falls in the river are over ledges of limestone and granite, and fairly good building marble is quarried. A small amount of iron ore is mined. There is also easily available a pure quartz sand which has become famous in the glass industry.

The country is prosperous, and the power facilities have attracted a skilled class of artisans. The principal industries are the manufacture of paper and woolen goods. The railroad facilities are very good.

Flow.—The flow of the river is fairly steady, because of the large storage area, which is partly natural and partly of artificial development. It is probable that the reservoir capacity has been developed to nearly its full extent. The approximate area of 35 ponds and reservoirs in the basin is 9,304 acres.

The principal ponds are Pontoosic Lake, Lanesboro, Mass., 313 acres; Onota Lake, Litchfield, Mass., 555 acres; Ashmere reservoir, Hinsdale, Mass., 310 acres; Washinee Lake, Salisbury, Conn., 400 acres; Washining Lake, Salisbury, Conn., 650 acres; Wononscopomus Lake, Salisbury, Conn., 355 acres; Quassapaug Pond, Middlebury, Conn., 535 acres; Bantam Lake, Litchfield, Conn., 1,070 acres; North Pond, Goshen, Conn., 300 acres.

There have been no gagings of the river extending over a period

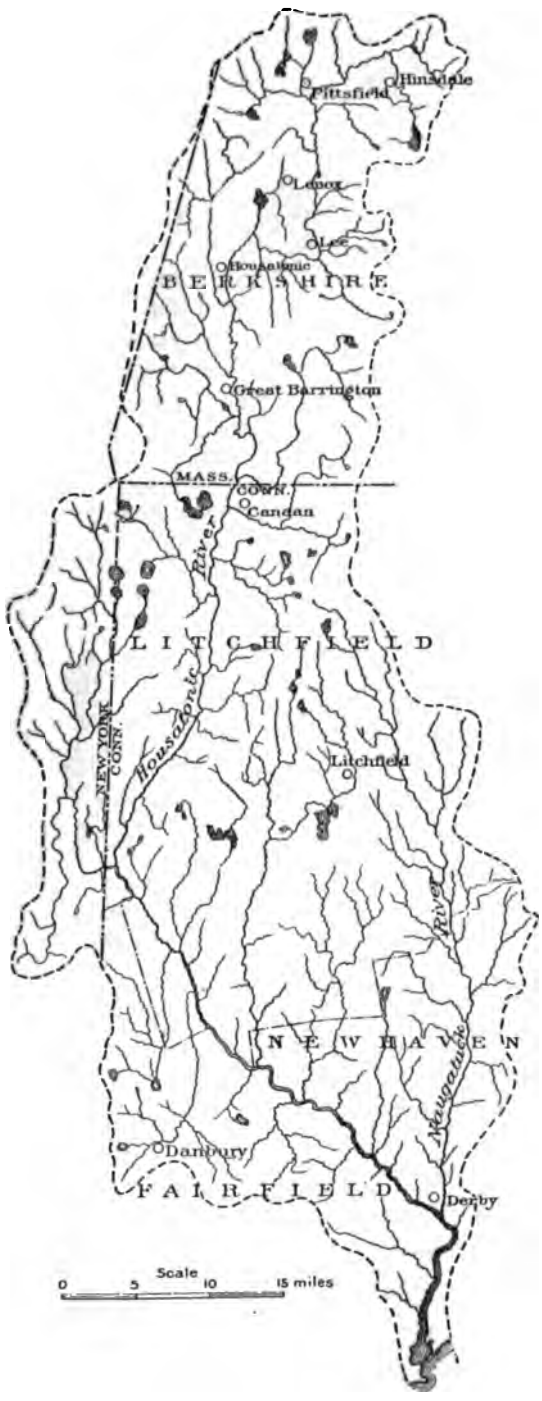


FIG. 11.—Housatonic River drainage basin.

sufficiently long to determine its flow with accuracy. In the year 1878 careful examinations were made from May to November at Kent, by the water department of New York, and the results probably show fairly well the summer flow of the river. According to these gagings the minimum flow for twenty-four hours was 260 cubic feet per second, while the average flow for the same period amounted to 460 cubic feet per second.

Water power.—After what has already been stated it is hardly necessary to say that the river may be valuable as a source of power. The total utilized horsepower on the whole system is about 18,884. In the main river the utilized horsepower is 6,434, and the remainder is distributed among the tributaries as follows: Naugatuck River, 4,909; Mad River, 1,220; Pomperaug River, 361; Shepaug River, 695; all other tributaries, 5,265.

The details of the power system are well set forth in the Tenth Census Report on Water Power, Vol. XVI.

NORMAL WATER IN THE HOUSATONIC BASIN.

The limestone formations in the Housatonic Basin make the water hard. In other respects the normal Housatonic water does not materially differ from that in the Connecticut Basin. The normal chlorine for this region varies from about 0.8 part per million at the upper end of the area to 3 parts near the mouth of the river.

The following table of analyses represents the averages of the results of various examinations of water made during the past decade.

TABLE 68.—*Analyses of various normal waters in the Housatonic drainage area.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
East Branch of Housatonic above Hinsdale.	Slight	2.0	0.138	0.036	0.001	0.180	0.8	54.0	....
Lake Oneota, Pittsfield	Very slight	0	.158	.000	.000	.030	.3	66.0	....
Pontoosuc Lake, Pittsfield.	do	0	.128	.006	.000	.000	.4	79.0	....
Egypt Brook, Dalton	do	2.9	.080	.002	.000	.196	.7	27.3	....
Green River, Great Barrington.	do	.....	.028	.005	.000	.225	1.0	74.1	56
Hinsdale storage reservoir.	do	2.1	.202	.017	.000	.017	.7	20.7	1
Upper reservoir, Berkshire Water Co.	do	3.9	.303	.056	.000	.027	1.0	26.7	4
Millbrook reservoir, Pittsfield.	do	.1	.095	.011	.000	.057	.9	53.5	40
Lake Averic, Stockbridge.	do	.8	.181	.021	.000	.022	.8	62.0	40
Padaranium reservoir, Danbury.	do	.3	.102	.030	.003	.09	1.95	47.7	13
Kent reservoir	do	.1	.080	.008	.000	.12	1.56	64.5	30
North Canaan	do	.02	.030	.004	.001	.05	1.25	111.6	98
Farm Brook	do	.4	.105	.022	.001	.11	1.84	80.2	12

POLLUTION IN THE HOUSATONIC.

The population in the Housatonic Basin has increased rapidly during recent years, and the consequent pollution has become a matter of grave consideration.

The East Branch of the Housatonic receives pollution from the manufacturing villages of Hinsdale and Dalton, which have a population of 1,485 and 3,014, respectively. The report of the State Board of Health for 1890 gives analyses of water collected below these villages which show a considerable increase in the amount of organic matter present. A comparison of the analyses in Table 69 with the first analysis presented in Table 68 will clearly show indications of sewage pollution.

TABLE 69.—*Analyses of water from East Branch of the Housatonic above Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
1888.								
Sept. 7	Slight	2.0	0.238	0.092	0.008	0.180	1.9	112
Do	Distinct	2.0	.390	.092	.003	.200	2.0	117.5

Although these analyses were made in the year 1888, the conditions now existing in the river compare very closely to those found in the year of the analyses. The population in this part of the drainage area has not increased materially and the analyses therefore fairly represent existing conditions.

TABLE 70.—*Analyses of water from the East Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	2.4	0.264	0.192	0.004	0.100	1.4	92.5	56
July 27	Decided	2.2	.416	.128	.006	.070	2.6	101.5	70
September 14	do	2.4	.244	.100	.009	.060	3.1	122.5	87
September 25	Very slight	2.2	.412	.168	.007	.100	3.0	126.5	91
October 23	Slight	3.0	.464	.196	.008	.120	3.9	135.5	97
November 20	Decided	4.0	.416	.060	.002	.190	2.4	98.5	63
December 18	Slight	2.1	.324	.106	.006	.310	2.3	106.5	79
Average		2.7	.369	.136	.006	.145	2.6	109.5	78

TABLE 71.—*Analyses of water from West Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	1.5	0.268	0.084	0.001	0.010	1.5	76.5	46
July 27	do	.8	.216	.004	.000	.000	2.4	83.5	53
September 14	Decided	1.5	.432	.008	.000	.020	2.8	92.5	66
September 25	do	2.0	.452	.012	.002	.010	3.2	104.0	66
October 23	do		3.260	.970	.000	.010	15.6	458.0	80
November 20	do	2.1	.410	.080	.003	.060	2.2	102.0	60
December 18	do	.8	.328	.140	.019	.090	1.8	103.5	70
Average		1.4	.821	.209	.031	.031	4.4	155.3	65

TABLE 72.—*Analyses of water from Southwest Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	0.9	0.376	0.372	0.016	0.040	2.3	96.5	61
July 27	do	1.4	.210	.100	.004	.060	1.2	137.5	103
September 14	Decided	1.3	.434	.064	.012	.020	1.8	154.0	96
September 25	do	1.2	.440	.092	.005	.010	2.5	144.0	94
October 23	do	1.5	.364	.304	.007	.080	2.6	180.5	123
November 20	do	2.0	.284	.180	.006	.340	2.3	180.0	126
December 18	None	.8	.072	.036	.002	.420	1.8	116.5	97
Average		1.3	.291	.166	.007	.159	2.0	144.3	101

The analyses set forth in Tables 70, 71, and 72 represent the character of the water furnished to the Housatonic River. It will be seen that every branch which contributes to form the main artery at Pittsfield is highly polluted, and therefore the Housatonic at the very outset is a badly damaged stream. The West Branch seems to be in *the foulest condition*, the East Branch closely following. Nearly all

the pollution in the West and Southwest branches is furnished by the city of Pittsfield. The upper reaches of these two streams remain in excellent condition.

Pittsfield, a city of 21,766 inhabitants, has a public water supply and a system of sewerage which empties into the three branches of the river. During the period in which the analyses in Tables 70, 71, and 72 were made a sewage-purification system for the city of Pittsfield was in course of construction, and when this is put into operation a large part of the sewage which now enters the river will be no longer a source of pollution.

Passing down the river we find that the next available analyses of Housatonic River water were made from samples taken at New Lenox, a point about 4 miles below Pittsfield. The drainage area of the river at this point is 145.6 square miles, the population being about 177 per square mile. The following table comprises the average result of monthly examinations of the water at this point since the year 1894:

TABLE 73.—*Analyses of water from Housatonic River at New Lenox.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	2.7	0.183	0.131	0.024	0.204	2.5	131.7	85
1895	2.6	.238	.183	.038	.173	2.5	117.3	84
1896	2.6	.192	.169	.036	.208	2.2	118.8	86
1897	3.2	.240	.159	.008	.203	1.9	107.9	75
1898	2.7	.223	.106	.008	.178	1.5	94.0	64
1899	2.0	.233	.197	.017	.132	2.3	107.6	74
1900	2.2	.278	.378	.018	.118	2.8	111.7	72

Comparison of Table 73 with the three preceding tables shows that very little change has taken place in the amount and character of the organic matter in the river after it has traversed the 4 miles above mentioned. The water seems to be fairly loaded with polluting material in every state of oxidation, and there seems to be extremely rapid decomposition going on. There is nothing of an unusual nature in the above series. They present and clearly indicate an abundant pollution, which, as we have seen, is borne out by facts.

Leaving New Lenox the river flows south past the town of Lenox, which has a population of 2,942. At this place there is a sewerage system, but it is provided with a disposal plant, so that the river does not receive a large increment of pollution. A few miles farther down

the river runs through the town of Lee, which contains 3,956 inhabitants. Considerable polluting matter is poured in at this point. Shortly below Lee the river makes a sharp turn eastward and flows through Stockbridge, a town which has a population of 2,031. A sewerage system is maintained at this point and filter beds have been provided, so that extensive pollution of the river is avoided.

TABLE 74.—*Analyses of water from Housatonic River at Stockbridge.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Very slight	1.1	0.312	0.284	0.016	0.070	2.9	120.5	9
July 31	do	.8	.198	.174	.014	.100	2.6	171.0	8
August 27	Decided	1.5	.240	.208	.026	.022	3.3	136.0	9
September 26	Very slight	1.2	.192	.072	.012	.110	3.9	135.0	10
October 23	do	1.5	.236	.228	.018	.220	4.4	166.5	11
November 21	Decided	3.5	.380	.208	.007	.210	3.7	123.5	8
Average		1.6	.260	.195	.005	.152	3.5	133.1	9

After leaving Stockbridge the river again turns south and flows through the town of Great Barrington which has a population of 5,854 and which contributes a large amount of pollution.

The next series of analyses made by the Massachusetts State Board of Health is of the water from the river at Sheffield, just north of the Connecticut State line. There seems to be considerable improvement in the water at this point over that at Stockbridge. The average of the six analyses of the water from the river made during the year 1900 is set forth in the following table:

TABLE 75.—*Average of six analyses of water from Housatonic River at Sheffield.*

[Parts per million.]

Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of samples.
	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1.6	0.214	0.079	0.004	1.93	2.8	128.2	90	6

The above average of analyses clearly indicates a fairly large degree of purification over that shown in Table 74. It will be seen that while the color and residue are practically the same, the free and albuminoid ammonia and the nitrites are considerably less, while the nitrates are higher—an unmistakable indication of oxidation. The chlorine, too, seems to be in smaller proportion, the river having been largely diluted by the influx of pure water.

Passing over into the State of Connecticut the Housatonic runs by or through the towns of Salisbury and North Canaan, where the population is almost entirely rural, although these places are rather thickly settled.

At Falls Village, a few miles south of the Massachusetts border, the Board of Health of the State of Connecticut has during the year 1900 been securing samples of water for analysis the results of which are set forth in the following table:

TABLE 76.—*Analyses of water from Housatonic River at Falls Village, Conn.*

[Parts per million.]

Date of examination.	Turbidity.	Color	Nitrogen as				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia	Nitrites.	Nitrates.			
1900.									
January 26	Slight	0.3	0.192	0.044	0.002	0.15	1.7	79.0	60
February 22	Distinct	.2	.102	.042	.002	.10	1.9	86.0	70
March 21	Very slight	.3	.170	.018	.004	.15	1.6	69.0	35
April 30	None	.2	.082	.046	.002	.05	1.8	67.0	75
May 17	Slight	.3	.188	.070	.008	.05	2.0	62.5	60
June 11	do	.2	.174	.090	.001	.10	2.1	111.0	90
July 5	None	.2	.112	.028	.003	.10	2.7	125.0	70
August 14	Slight	.1	.118	.024	.002	.18	2.9	131.0	63
September 12	do	.3	.207	.026	.004	.13	2.1	115.0	55
October 10	do	.2	.100	.020	.002	.13	4.0	145.5	68
November 13	do	.4	.148	.012	.002	.22	3.3	139.5	53
December 10	do	.4	.146	.034	.006	.20	1.6	106.0	59
Average		.3	.150	.038	.003	.13	2.3	103.0	63

Comparison of the above series with that made of the water at Sheffield, Mass., shows a still further purification. In some respects the water at Falls Village is considerably better than at any point since it received its first contamination at Pittsfield. One can not fail to be impressed with the fact that the Housatonic has excellent

powers of recovery, and it is very likely that if the sewage of the various towns along its banks is submitted to proper treatment the river will approach nearly its normal purity.

The State Board of Health of Connecticut has conducted another series of analyses of the water at a point 65 miles below the town of Falls Village, at the town of Derby, just below where the Naugatuck joins the river. In passing from Falls Village to Derby the Housatonic goes by the towns of Sharon, Cornwall, Kent, New Milford, Bridgewater, Brookfield, Roxbury, Southbury, Oxford, Newton, Monroe, Seymour, and Huntington. All these municipalities contain from 1,000 to 3,000 inhabitants, and contribute an amount of contamination usual in such cases. In addition to these towns there is the city of Danbury, with a population of 16,000, which contributes raw sewage in large amount. In spite of this additional pollution, however, the analysis made at Derby shows very little change in the character of the water.

TABLE 77.—*Analyses of water from Housatonic River at Derby.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.								
January 29	0.3	0.122	0.052	0.002	0.10	2.3	79.0	60
February 21	.3	.108	.040	.002	.10	2.1	60.0	40
March 21	.3	.128	.050	.040	.15	1.9	51.5	27
April 26	.3	.124	.036	.002	.05	2.3	75.5	45
May 17	.3	.108	.060	.006	.15	1.9	80.5	70
June 11	.3	.100	.078	.002	.15	2.3	99.0	80
July 5	.2	.144	.050	.002	.05	2.4	108.5	70
August 24	.2	.140	.040	.000	.10	2.3	115.5	57
September 11	.2	.144	.026	.060	.05	2.8	116.5	91
October 10	.1	.144	.036	.001	.10	3.6	116.0	58
November 4	.5	.188	.016	.004	.19	3.5	113.5	36
December 10	.4	.168	.006	.006	.20	1.9	82.5	43
Average	.3	.136	.042	.008	.13	2.44	91.5	56

Below Derby the Housatonic receives the polluted water of its principal tributary, the Naugatuck, and flows thence into Long Island Sound. We have now traced the river from its source in Massachusetts to its mouth, and have found that from its headwaters it is

lluted to a sufficient extent to entirely unfit it for a source of water pply unless the water is filtered. This, however, is about as far as mage extends. Although considerable sewage enters the river at fferent points, such is the dilution and such the purifying capacity at it does not, except at a few points, betray its contamination, cept by chemical analyses. As it crosses from Massachusetts into onnecticut it is in a condition which makes its use by the people of onnecticut as a source of water supply impossible without filtration. is probable that the Housatonic River will in the future be conantly improved by the removal of sewage contamination through the stablishment of purification works at the various points of pollution.

COURT DECISIONS IN CONNECTICUT.

The opinion of the supreme court of errors of the State of Connecticut in a suit at law against the city of New Britain, arising from the ollution of a watercourse, has already been cited. The courts of Connecticut have taken no uncertain stand on the question of river ollution. In no other State in the Union has there been such inequivocal judicial disapproval of the practice of destroying water esources, and as future work along this line will probably result in frequent reference to the Connecticut cases it seems wise to review briefly the different decisions which have been rendered.

The case of Morgan *v.* The City of Danbury is of interest, inasmuch as it involves a decision against a city which had provided a purification plant for the disposal of sewage. The plaintiff, a riparian owner and a mill proprietor on Still River, complained in the superior court that the defendant, without making him any compensation or attempting to acquire any of his rights, did discharge and was continuing to discharge into that river wastes, sewage, and other noxious substances, and prayed for an injunction against the continuance of that practice.

Danbury is a city of 20,000 inhabitants, situated on Still River, a small sluggish stream which empties into the Housatonic 16 miles below. In 1885 a system of sewerage was constructed which emptied directly into Still River. By the year 1890 the use of the sewers had increased to such an extent as to cause a local nuisance. In 1893 an outfall sewer was completed which conducted the sewage 1 mile below the city. During the summer seasons Still River has scarcely any flow, and the Woolf disinfecting system was installed in 1894, for use during the dry stages of the river. It consisted of large vats of brine, from which a solution known as hyperchloride of sodium was developed by electric currents.

An injunction was granted against further discharge of sewage. An appeal was taken.

The case was reviewed by the supreme court of errors in the January term *in the third* judicial district, 1896, and following are

extracts of the opinion of the court handed down by Associate Justice Baldwin (67 Conn., 484):

The complaint alleged that the city was discharging waste matter, sewage, other noxious, corrupt, and impure substances from its sewers so as to pollute the river and to cause much of such discharges to be deposited on the plaintiff's land and mill privilege; and that thereby he had been largely deprived of the use of a valuable mill and mill privilege, he and his workmen injuriously exposed to noxious odors, the air in the neighborhood corrupted and poisoned so as to endanger the health of himself and others, his milldam partly filled up with filth, the value of his property greatly diminished, and he disabled from disposing of his land for building purposes. * * *

These allegations were denied, but have been found true; and there is nothing inconsistent with their truth in the special finding of facts. * * * It was proper that an injunction should be so framed as to protect the plaintiff against every serious and irreparable injury which he might suffer by the continuance of the nuisance, and its terms are fully conformable to the claims stated in his complaint.

* * * The supplemental answer, setting up the establishment of the Woodbridge disinfecting plant, avers that the discharges from the sewer have thereby been rendered "entirely harmless and free from any offensive qualities, and no solid matter is permitted to empty from said sewer into said stream, but the same is liquefied and clarified and the plaintiff is relieved thereby of all danger in the future from the said sewer." * * * These allegations were denied, and the issues upon them have been found for the plaintiff.

* * * It is not impossible that fluids discharged from the sewer, although colorless, sterilized, and apparently innoxious, may yet be such as, by combination with other substances found in the river, to become the occasion of decomposition and consequent pollution. * * *

The defendant urges that it should not be made responsible for the acts of others, and that if its sewage is thoroughly disinfected, sterilized, and purified before its discharge into the river, nothing further should be required, even though, as it flows down the stream, it may be brought into contact with other substances in such a way as to work a nuisance. But the right to deposit a thing in any place must always be dependent, not only on its own nature but on the nature of the place in question and the uses to which that has already been put.

In a similar suit brought by Platt Bros. & Co., to restrain the city of Waterbury from polluting Naugatuck River above the complainant's mill, the superior court rendered judgment for $500, and an injunction was issued. Appeal was made by the State to the supreme court of errors, and a decision was handed down January 4, 1900, by Associate Justice Hammersley. This opinion deals so clearly and admirably with that oft-repeated contention of municipal authorities that a city is not liable for damages because of sewage, if it has been authorized to turn the same into a stream by an act of the legislature, that a large part of the decision will be given here (72 Conn., 531):

The main contention of the defendant may be stated in this way: The use of the sewers, under authority of the legislature, in the manner described, is a public, governmental use; the injuries to the plaintiffs result from this governmental use and are not direct but merely consequential; the victim of consequential injuries resulting from a governmental use is entitled to no remedy unless one is given by *statute; the* defendant's charter provides no remedy for consequential injuries

resulting from the use of said sewers; ergo, the plaintiff has no remedy, and its damage is damnum absque injuria.

The premises essential to this conclusion are untrue. A governmental use may include any act which the State may lawfully perform or authorize. There are, however, governmental acts to which certain immunities attach; and it is with this restricted meaning that the phrase is used by the defendant. In this sense a governmental act is one done in pursuance of some duty imposed by the State on a person, individual or corporate, which duty is one pertaining to the administration of government, and is imposed as an absolute obligation on a person who receives no profit or advantage peculiar to himself from its execution. It is the State, exercising its governmental power through an agent who, in this matter, is the agent of the State and nothing more. It is to be distinguished from a large class of governmental acts which the State, by way of grant or special privilege, authorizes persons to perform in part for their personal benefit. The principal immunities belonging to a governmental act, in this restricted sense, are: (1) Freedom from personal responsibility for the consequences of the act alone. So long as a lawful mandate of the State is faithfully executed, the agent acting within the scope of that authority enjoys the exemption from suit which belongs the State. (2) Freedom from personal responsibility for the negligence of his servants. The rule of respondeat superior does not apply, because the agent of the State is not the superior; the real superior is the State itself.

The defendant claims these immunities. It may be doubted whether the use of sewers under the charter of the defendant, for the collection and disposition of refuse belonging to its citizens, is a governmental act within the definition given. The charter authorized the construction of sewers for that purpose, but no absolute duty was imposed upon the city; action in pursuance of the authority was at its option and could not have been enforced by any process of law without further legislation. While sewers or drains for the disposition of surface waters collecting in highways may be considered as mere adjuncts of a highway, partaking of its nature as a governmental use (Cone *v.* Hartford, 28 Conn., 363, 372), it is different with sewers for the disposition of refuse and filth accumulated upon private property. The disposition of such stuff is in part for the benefit of the property holder. The city represents, in such respects, the interests of its inhabitants, and is granted certain special powers, in part for the promotion of their interests (Bronson *v.* Wallingford, 54 Conn., 513, 519). It is well settled that there is a clear distinction between those governmental duties imposed upon a city as a mere agent of government and those governmental powers granted as a privilege primarily for the personal benefit of its inhabitants. * * * We think it evident that the mere granting authority to a city to construct, for the convenience and benefit of its inhabitants, sewers adapted to carry off their refuse matter to some neighboring stream, does not necessarily make such use of the sewers a governmental use in the sense indicated. * * *

But if, for the purpose of this case, we concede the defendant's claim that the use is a governmental use, it is nevertheless liable to the plaintiff. The injury described by the complaint is not a mere consequential damage, like that resulting wholly from the lawful use of one's own property, or the lawful exercise of governmental power; it is a direct appropriation of well recognized property rights within the guarantee of the Constitution—"The property of no person shall be taken for public use without just compensation therefor" (Nolan *v.* New Britain, supra, p. 681), and so the defendant's claim that its charter does not authorize the condemnation of the plaintiff's property rights is immaterial. Upon a careful examination of the charter as enacted in 1871 (7 Special Acts, 206) and amended in 1881 (9 id., 233 et seq., 237), in 1883 (9 id., 839), and in 1884 (9 id., 954), and applying the rule which requires a law to be so construed, if reasonably possible, as to

give it validity, we think the city is authorized to make compensation by agreement or after appraisal, for any private property taken for the purpose of the maintenance and use of the sewers authorized. But if it were otherwise, the defendant would not be benefited. Its whole defense of acting under lawful State authority would then fail, and the mere finding of the facts alleged in the complaint would clearly support the judgment.

The defendant's brief presents its claim in a form somewhat different from that stated in the finding, and certainly novel in this State. It is substantially this: (1) A riparian city has a right to use the river for certain drainage, and such surface drainage necessarily pollutes the water to some extent, increasing with the growth of the city. (2) The use of these legitimate drains to carry off the noxious refuse accumulated by its inhabitants becomes in time an absolute necessity. (3) The right of surface drainage is thereby enlarged so as to include the right to discharge into the river, by means of these drains, such noxious refuse. Therefore the necessities of municipal growth give the city a right to convey these noxious substances to the property of downstream proprietors, and so to appropriate that property for public use without compensation.

It is unnecessary now to discuss the limitations to the right of surface drainage, for the second and third propositions are clearly wrong. The right to pour into the river surface drainage does not include the right to mix with that drainage noxious substances in such quantities that the river can not dilute them nor safely carry them off without injury to the property of others. The latter act is, in effect, an appropriation of the bed of the river as an open sewer, and the proposition that it may become lawful by reason of necessity is inconsistent with undoubted axioms of jurisprudence. The appropriation of the river to carry such substances to the property of another is an invasion of his right of property. When done for a private purpose it is an unjustifiable wrong. When done for a public purpose it may become justifiable, but only upon payment of compensation for the property thus taken. Public necessity may justify the taking, but can not justify the taking without compensation. It may be necessary for a city to thus mix with its drainage such substances, but it is not necessary to pour such mixture into the river without purification; indeed, the purification is coming to be recognized as a necessity. But however great the necessity may be, it can have no effect on the right to compensation for property taken. The mandate of the Constitution is intended to express a universally accepted principle of justice, and should receive a construction in accordance with that principle, broad enough to enable the court to protect every person in the rights of property thus secured by fundamental law.

There are certain apparent, but not real, exceptions to this protection. Emergencies may be such as to justify the taking of property without waiting to provide for compensation; property may be destroyed without compensation in certain cases when used unlawfully, or when it has become a thing of danger. But this is not a case of war or conflagration. The plaintiff has not so used its property as to subject it to the harsh police power of confiscation. The plaintiff has certain rights as a riparian landowner. These rights are property within the meaning of our constitutional guaranty, and an invasion of these rights such as the defendant has made is a taking of that property. The legislature has no power to authorize such taking except for public use, and then only upon providing for just compensation. (Kellogg *v.* New Britain, 62 Conn., 232, 239; Wadsworth *v.* Tillotson, 15 id., 366, 373; Harding *v.* Stamford Water Co., 41 id., 87, 93; Nolan *v.* New Britain, 69 id., 668, 681; Fisk *v.* Hartford, 70 Conn., 720, 731; Seifert *v.* Brooklyn, 101 N. Y., 136; Chapman *v.* Rochester, 110 id., 273, 277.)

An action for fouling a brook and mill privilege by the discharge of sewage, with a claim for damages and an injunction against the town of New Milford, was brought by Joseph E. Watson et ux. in the

superior court in Litchfield County, and on trial by the court (Shumway, J.) an injunction was refused and judgment was rendered for the plaintiff for $50 damages. An appeal was taken by the defendant for alleged errors in the rulings of the court. No error.

The finding stated these facts:

The plaintiffs' land is situated on Great Brook, in New Milford. There are no buildings on it. To use it for buildings would require some previous filling on a part of it. It has been used for pasturage, and partly for cultivation, but yields now little income. The annual rental value is $75, and has not been substantially affected by the fouling of the brook. The court, at the request of the parties, viewed the premises, in the summer, when the water was low, and saw on the margin of the brook a sediment giving off odors of putrefying sewage, unwholesome and offensive, and also undissolved constituents of house sewage lying on the ground, offensive to the sight. At times of high water such conditions would not exist.

Since 1876 the sewage from the town hall had been discharged through a drain constructed by a village improvement association into Great Brook above the plaintiffs' land. In 1893 all the school districts in the town were consolidated, and the town took charge of the public schoolhouses then erected. One of these then discharged its sewage into Great Brook, and has ever since.

The plaintiffs lived seven miles from their land in question. The waters of the brook, where it runs through it, are potable by cattle, and there are trout in it. This water privilege has no value in its present condition.

In 1893 the defendant extended certain sewers through the plaintiffs' land and into the brook thereon, and has since maintained the same. These serve to carry off the surface water from the streets, and also house sewage. Various houses have been connected with them for the discharge of their sewage into them, with the knowledge of the selectmen.

The town, by its use of the brook as a means of getting rid of the sewage from the town hall and schoolhouse, has, in connection with its use by citizens for carrying off sewage from their houses, caused the state of things viewed by the court. The damage thus caused is not irreparable, but an injunction would be a proper remedy to prevent multiplicity of suits, should the town continue such use of the plaintiffs' premises for an unreasonable length of time hereafter. It was not found that the nuisance had prevented them from effecting a sale of the property.

The case was reviewed by the supreme court of errors in the January term, in the first judicial district, 1900, and the following extract is from the decision handed down January 19, 1900, by Associate Justice Baldwin (72 Conn., 561):

A nuisance was created upon the plaintiffs' land by the deposit of sewage and sediment from sewage, offensive from its appearance or its smell. The use of the sewers which receive the surface drainage from highways, and of that built by the village improvement association, by the defendant, to carry off the sewage from its public buildings, contributed to this injury. That others also contributed to it, and perhaps more largely, did not relieve the town from liability. (Morgan *v.* Danbury, 67 Conn., 484, 496.)

That the plaintiffs suffered no personal inconvenience from the nuisance, because they did not reside in the vicinity, is immaterial. They were entitled to nominal damages, at least, for the offensive condition of things upon their land, even if they never visited it, and although its rental and selling value remained unimpaired. (*Watson v. New Milford* Water Co., 71 Conn., 442.) If those assessed

can be regarded as substantial, they are still so small in amount that no new trial should be granted for their reduction. (Buddington *v.* Knowles, 30 Conn., 26; Holbrook *v.* Bentley, 32 id., 502, 508.)

The action was well brought against the defendant as a town, and not as a consolidated school district. It is a single corporation, and the consolidation simply threw upon it additional powers and duties. It maintained as a town a nuisance previously created by a district.

That the plaintiffs in prior years had discharged sewage and dyes from a hat shop on their premises into the brook did not bar their right of recovery. If they had thus fouled the brook to the injury of landowners below them, it did not operate as a license to landowners above them to use it in a similar way.

That the water remained potable by cattle and inhabitable by fish was unimportant except in mitigation of damages.

DELAWARE RIVER.

The Delaware drainage area occupies parts of the States of New York, New Jersey, and Pennsylvania, comprising 6,855 square miles. (See fig. 12.) The main river of the Delaware system rises in New York State, in a county bordering the western part of the Catskill Mountains. The elevation at that point is said to be about 1,900 feet. It flows in a very irregular course, its general direction being southward, and empties into Delaware Bay. For about 100 miles above Port Jervis it forms the boundary between the States of New York and Pennsylvania; below that point it forms the entire western boundary of the State of New Jersey.

The principal tributaries of Delaware River enter from the west. They consist of the Schuylkill, which joins the main stream at Philadelphia, draining a country 1,912 square miles in extent; and, a little farther north, the Lehigh, at Easton, the basin of which, 1,332 square miles in extent, comprises a great mining region of Pennsylvania. The Lackawaxen River enters at Lackawaxen, draining in its course 597 square miles. At the extreme northwestern part of the Delaware basin the river forks into the East and West branches, which drain 520 and 348 square miles, respectively.

Although the drainage basin of the Delaware is a very important, prosperous, and thickly-settled region, the resources of the river system have not been utilized or appreciated to any considerable extent, and comparatively little has been done to determine the character of the water. At Philadelphia the city is now conducting extensive investigations, which, when their results become available, will furnish a clear insight into the character of the water in the Schuylkill and Delaware opposite that city. Aside from these investigations, the results of which can not be learned at present, the only data available are comprised in a short report, by Mr. Allen Hazen, on the character of the water supply of the city of Trenton, N. J., which demonstrated beyond controversy that the water of the Delaware above the city of Trenton is polluted with sewage and industrial refuse to a dangerous *degree.*

FIG. 12.—Delaware River drainage basin.

The following table, taken largely from Mr. Hazen's report, gives the names of the municipalities in the Delaware Basin above Trenton contributing polluting substances to the river:

TABLE 78.—*Cities and towns above Trenton contributing polluting substances to Delaware River.*

[Drainage area, 6,916 square miles.]

City or town.	County.	Distance above Trenton.	Population, 1900.
		Miles.	
Lambertville, N. J	Hunterdon	14	4,637
Newhope, Pa	Bucks	14	1,318
Frenchtown, N. J	Hunterdon	30	1,080
Quakertown, Pa	Bucks	42	3,014
Phillipsburg, N. J	Warren	47	10,939
South Easton, Pa	Northampton	48	25,238
Easton, Pa	do	48	
Bangor, Pa	do	56	4,106
Nazareth, Pa	do	58	2,304
Bethlehem, Pa	do	59	7,293
South Bethlehem, Pa	do	59	13,241
West Bethlehem, Pa	Lehigh	60	3,465
Washington, N. J	Warren	60	3,580
Belvidere, N. J	do	62	1,784
Allentown, Pa	Lehigh	64	35,416
Penn Argyl, Pa	Northampton	65	2,784
Catasauqua, Pa	Lehigh	67	3,963
Oxford, N. J	Warren	71	3,095
East Stroudsburg, Pa	Monroe	71	2,648
Slatington, Pa	Lehigh	79	3,778
Stroudsburg, Pa	Monroe	81	3,450
Lehighton, Pa	Carbon	90	4,629
East Mauchchunk, Pa	do	93	3,458
Mauchchunk, Pa	do	93	4,029
Summithill, Pa	do	95	2,996
Nesquehoning, Pa	do	98	2,862
Waverly, Pa	do	100	2,471
Newton, N. J	Sussex	105	4,376
Whitehaven, Pa	Luzerne	115	1,517
Hazleton, Pa	do	115	14,230
Port Jervis, N. Y	Orange	120	9,385
Hawley, Pa	Wayne	157	1,925
Honesdale, Pa	do	166	2,864

78.—*Cities and towns above Trenton contributing polluting substances to Delaware River*—Continued.

City or town.	County.	Distance above Trenton.	Population, 1900.
		Miles.	
ck, N. Y	Delaware	194	1,883
it, N. Y	do	205	2,051
n, N. Y	do	228	2,811
, N. Y	do	245	2,078

lthough only a few of the municipalities mentioned in the above e have been provided with sewers, and the pollution is therefore n early stage of its development, the effects are noticeable in the owing analyses, which were made during the period of Mr. Hazen's estigation:

TABLE 79.—*Analyses of water from Delaware River at Trenton.*

[Parts per million.]

ate.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
. 16	3	0.15	0.060	0.004	0.000	0.260	1.7	44.50	23.0	6.0	0.30
e 29	680	.18	.350	.040	.004	.160	1.6	480.00	27.0	8.0	11.80
y 6	7	.12	.088	.042	.003	.320	2.2	93.00	42.0	9.5	.05
y 27	480	.12	.226	.086	.004	.160	2.0	273.00	27.0	9.5	8.00
ç. 17	3	.11	.102	.018	.006	.160	2.8	116.00	57.0	7.5	.20
t. 13	8	.08	.116	.024	.004	.160	3.0	103.00	57.5	14.0	.30

The investigation included a daily determination of turbidity from ril to November, inclusive, in the year 1889, the results of which ow that the Delaware water is usually free from suspended matter, d that, although it carries along considerable mud during freshets, sidence is rapid.

The following table, taken largely from Mr. Hazen's report, gives the names of the municipalities in the Delaware Basin above Trenton contributing polluting substances to the river:

TABLE 78.—*Cities and towns above Trenton contributing polluting substances to Delaware River.*

[Drainage area, 6,916 square miles.]

City or town.	County.	Distance above Trenton.	Population, 1900.
		Miles.	
Lambertville, N. J	Hunterdon	14	4,687
Newhope, Pa	Bucks	14	1,218
Frenchtown, N. J	Hunterdon	30	1,020
Quakertown, Pa	Bucks	42	3,014
Phillipsburg, N. J	Warren	47	10,050
South Easton, Pa	Northampton	48	25,238
Easton, Pa	do	48	
Bangor, Pa	do	56	4,106
Nazareth, Pa	do	58	2,304
Bethlehem, Pa	do	59	7,293
South Bethlehem, Pa	do	59	13,241
West Bethlehem, Pa	Lehigh	60	3,465
Washington, N. J	Warren	60	3,580
Belvidere, N. J	do	62	1,784
Allentown, Pa	Lehigh	64	35,416
Penn Argyl, Pa	Northampton	65	2,784
Catasauqua, Pa	Lehigh	67	3,968
Oxford, N. J	Warren	71	3,095
East Stroudsburg, Pa	Monroe	71	2,648
Slatington, Pa	Lehigh	79	3,778
Stroudsburg, Pa	Monroe	81	3,450
Lehighton, Pa	Carbon	90	4,629
East Mauchchunk, Pa	do	93	3,458
Mauchchunk, Pa	do	93	4,029
Summithill, Pa	do	95	2,986
Nesquehoning, Pa	do	98	2,869
Waverly, Pa	do	100	2,471
Newton, N. J	Sussex	105	4,376
Whitehaven, Pa	Luzerne	115	1,517
Hazleton, Pa	do	115	14,230
Port Jervis, N. Y	Orange	120	9,385
Hawley, Pa	Wayne	157	1,925
Honesdale, Pa	do	166	2,864

78.—*Cities and towns above Trenton contributing polluting substances to Delaware River*—Continued.

City or town.	County.	Distance above Trenton.	Population, 1900.
		Miles.	
ock, N. Y	Delaware	194	1,883
ait, N. Y	do	205	2,051
on, N. Y	do	228	2,811
. N. Y	do	245	2,078

though only a few of the municipalities mentioned in the above have been provided with sewers, and the pollution is therefore early stage of its development, the effects are noticeable in the wing analyses, which were made during the period of Mr. Hazen's stigation:

TABLE 79.—*Analyses of water from Delaware River at Trenton.*

[Parts per million.]

e.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
16	3	0.15	0.060	0.004	0.000	0.260	1.7	44.50	23.0	6.0	0.30
29	680	.18	.350	.040	.004	.160	1.6	480.00	27.0	8.0	11.80
6	7	.12	.088	.042	.003	.320	2.2	93.00	42.0	9.5	.05
27	480	.12	.226	.086	.004	.160	2.0	273.00	27.0	9.5	8.00
17	3	.11	.102	.018	.006	.160	2.8	116.00	57.0	7.5	.20
13	8	.08	.116	.024	.004	.160	3.0	103.00	57.5	14.0	.30

ne investigation included a daily determination of turbidity from il to November, inclusive, in the year 1889, the results of which v that the Delaware water is usually free from suspended matter, that, although it carries along considerable mud during freshets, idence is rapid.

TABLE 80.—*Turbidity of Delaware River at Trenton.*

Day of month.	April.	May.	June.	July.	Aug.	Sept.	Oct.	No
1	.....	6	6	9	13	6	6	
2	.....	6	6	9	13	6	6	
3	.....	6	9	6	9	6	6	
4	.....	6	9	6	13	6	6	
5	.....	6	9	6	6	6	6	
6	.....	6	9	6	6	6	6	
7	.....	6	9	6	6	6	6	
8	.....	6	6	28	6	6	6	
9	6	6	6	13	6	6	44	
10	6	6	6	9	6	6	6	
11	6	6	6	6	6	6	6	
12	6	6	6	6	6	6	6	
13	6	6	6	6	6	6	6	
14	6	6	6	6	16	6	400	
15	6	6	77	6	6	6	100	
16	6	6	77	6	6	150	56	
17	6	6	32	6	6	32	13	
18	6	6	32	6	6	20	6	
19	32	2,737	28	6	6	13	6	
20	28	28	16	6	6	9	6	
21	16	28	9	6	6	9	6	
22	16	28	6	6	6	6	6	
23	16	24	6	6	6	6	6	
24	16	24	6	6	6	6	6	
25	13	9	6	6	6	6	6	
26	13	9	6	28	6	6	6	....
27	13	9	6	77	6	6	6	....
28	9	9	236	56	6	6	6	....
29	9	9	16	40	6	6	6	....
30	6	6	16	32	6	6	6	....
31	.....	6	.....	150	6	.....	6	....

OHIO RIVER BASIN.

DRAINAGE AREA.

A clear and concise description of the drainage area of the Ol River is given in the report of Prof. Dwight Porter, published Volume XVII of the Report of the Tenth Census, as follows:

By the union of the Allegheny and Monongahela rivers at Pittsburg the Ol River is formed, with a drainage basin at that point of between 18,000 and 19,(*square miles*, which, after a course of nearly a thousand miles to the southwe

is increased to about 214,000 square miles at the junction with the Mississippi. The principal streams which contribute to this increase are, on the north side, the Beaver, Muskingum, Scioto, Great Miami, and Wabash rivers, and on the south side the Little Kanawha, Great Kanawha, Big Sandy, Licking, Kentucky, Green, Cumberland, and Tennessee. The headwaters of the Allegheny are in northern Pennsylvania and southwestern New York; those of the Monongahela, nearly 250 miles distant, in West Virginia. The eastern watershed line of the Ohio therefore cuts directly across the State of Pennsylvania, at a distance from the western border ranging from 80 miles in the south to about 130 miles in the north. Passing out of this State, the northern boundary of the river basin runs through New York, Ohio, and Indiana, being carried in the latter State around the upper waters of the Wabash nearly to the Michigan line and considerably more than 200 miles north of the main river itself; it then enters Illinois and strikes southerly through that State to the mouth of the Ohio at Cairo. The southern boundary runs from Pennsylvania across a corner of Maryland, embraces nearly all of West Virginia, and forms in part the dividing line between that State and Virginia; it crosses the southwestern portion of the latter State and the western part of North Carolina, and by the Tennessee Basin is extended down into Georgia and Alabama, reaching there a distance of 300 miles south of the Ohio; it continues from Alabama across the adjacent northeastern corner of Mississippi, and finally traverses the extreme western portions of Tennessee and Kentucky.

The characters of the different streams within this area are determined or modified by the various topographic features of the country. In the east and southeast the drainage area is bordered by the Allegheny Mountains, and the streams which have their origin there flow into the Ohio through a generally sparsely settled country rich in mineral deposits. From this region across to Mississippi River the surface grows flatter, rapidly in some directions, more gradually in others. Toward the Ohio there is a gradual decline in elevation, culminating in the bottom lands along that river, which have become famous for their fertility. North of Ohio River the land comprising that portion of the basin lying within the States of Ohio and Indiana rises very slowly, through many miles of undulating territory, and ends in a low range of hills which forms the divide between the Ohio Basin and the drainage area of the Great Lakes.

The various tributaries on the south side of the Ohio offer facilities for extensive development of power. The descent of the streams is swift, especially in the southern portion, but the flow is extremely variable, the drainage areas being of the "quick-spilling" variety, and consequently enormous pondage would be necessary to secure any great measure of uniformity of flow. In the case of some streams this would make the initial cost of utilization extraordinary and prohibitive. On the north side of the Ohio the country is flat and the proportion of run-off is small, so that, as a whole, the streams are not well adapted for the development of power. It is true that there has been considerable utilization of streams for local grist and lumber mills, yet it is not at all proportional to the contributing drainage area as compared with that which is possible on the streams of New

York and New England. The Ohio is therefore in only a comparatively limited sense a power stream.

The main river has great value as a channel of transportation, and some of the tributaries are navigable to a limited extent. This value has been developed largely by the Federal Government.

CHARACTER OF WATER.

In considering the characteristics of the waters of the Ohio Basin one can not fail to be impressed with the marked differences which exist between them and the waters of the Northeastern States, already considered at length. In the latter region we have studied waters which are, as a rule, fairly clear, which contain only small amounts of dissolved mineral matter, and in which the degree of hardness is usually almost insignificant. We have noted that the New England waters are highly colored, some extremely so, from the solution of chlorophyll and decaying vegetable and peaty matter. This characteristic has led to the application to these waters of the apt and expressive term "vegetable tea." In considering the water in the Ohio Basin it is necessary to remember in the beginning that we have to deal with a water which usually contains a high proportion of inorganic salts, which is hard, and which in times of freshet carries along enormous quantities of fine clay and mud. A report of a water analysis which, in the case of a New England water, would be regarded as certain evidence of artificial pollution, may in the case of Ohio water represent a truly normal river of uncontaminated and healthful character.

The following analyses illustrate this point:

TABLE 81.—*Comparison of analyses of normal waters in New England and in the Ohio Basin.*

[Parts per million.]

	Region.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1	Massachusetts	Very slight.	6.6	0.199	0.013	0.000	0.037	1.7	34.7	8.0
2	Ohio Basin	do	4.0	.514	.062	.024	1.500	2.0	730.0	43.6

Sample No. 1 in the above series was a normal water taken from an upland stream in Massachusetts. It is a fair representative of Eastern waters, having some turbidity, a high color, and considerable organic matter, as is shown by the nitrogen compounds. Sample No. 2 was a normal water taken from an upland region in the Ohio Basin

above all points of contamination. It also is a good representative of waters of its class, having a moderate color, a large residue, and an extremely high content of nitrogen, especially in the form of nitrates. Note also that the water is very hard. From the standpoint of sewage pollution both of the above samples are equally good, each being uncontaminated. From the sanitary standpoint No. 2 is the equal of No. 1, and if these analyses faithfully represented the character of the streams from which these samples come the resources of one would be equal to those of the other, other things, of course, being equal.

Another point to be borne in mind is the extreme variability of the physical characteristics of the Ohio Basin waters, especially the turbidity. In a time of drought the water will be clear, but soon after a rainstorm the turbidity will rise to a point which almost defies clarification, but in the course of a few days the water will become as clear as it was before the storm.

ALLEGHENY RIVER.

GENERAL FEATURES.

Drainage area.—The Allegheny is the largest contributor to the Ohio. (See fig. 13.) The drainage area covers 11,400 square miles and lies principally in the State of Pennsylvania, extending for a short distance into the State of New York. The length of the stream is about 325 miles, and its basin embraces a large area of the western slope of the Allegheny Mountains. The country is rough and broken, with high summits and deep valleys.

Water power.—The Allegheny is not very valuable as a source of water power. The storage capacity in the drainage area is extremely small; and although in early times the large number of springs maintained a fairly constant flow, the deforestation has reduced the whole area to a "quick-spilling" country. Although the drainage area is large, only a small portion of it contains streams that are valuable for development of power. The river is peculiar in this respect, for the descent is more rapid in the middle and lower portions than it is at the headwaters. In those portions it is deep and is used extensively for transportation, but above the head of navigation it has little value. The power which has been developed is applied mainly to the lumber industry.

Flow.—The flow of the Allegheny has not been definitely determined, and the figures available to show it are not the result of as careful and long-continued measurement as is generally considered necessary for the accurate determination of flow.[a] Measurements made in 1897 under the direction of a corps connected with the War Department seem to show that the flow of the Allegheny at Franklin

[a] See *Twentieth Annual* Rept. U. S. Geol. Survey, Part IV, p. 95.

was about 1,000 second-feet, and at another point 20 miles below a d
charge of 1,250 second-feet was determined. In the year 1838 t
discharge of the Allegheny at Pittsburg was reported as being 1,
second-feet, while various gagings during the years 1866–1870 show

FIG. 13.—Allegheny River drainage basin.

that at Brunots Island, 2½ miles below the junction of the Allegh
and the Monongahela rivers, the least discharge was 1,700 second-fe

POPULATION OF BASIN.

In the drainage basin of Allegheny River the population l
increased rapidly. The following table includes the most impor

and towns, their population in 1890 and 1900, and their approx-
distance from the city of Pittsburg:

82.—*Cities and towns on Allegheny River and tributaries above Pittsburg.*

Place.	Distance in miles.	Population.		Place.	Distance in miles.	Population.	
		1890.	1900.			1890.	1900.
a	3	1,477	1,904	Titusville	142	8,073	8,224
ont	4	1,678	2,323	Meadville	144	9,520	10,291
Kensington	11	.....	4,665	St. Marys	148	1,745	4,295
itum	14	4,627	5,472	Johnsonburg	149	1,280	3,894
ort	21	1,637	1,754	Wilcox	151	.....	.....
City	33	1,255	2,870	Tidioute	160	1,328	1,237
o	35	2,156	2,924	Edinboro	161	1,107	691
nning	38	3,095	3,902	Waterford	170	838	767
urg	47	1,088	828	Sheffield	172	2,202	2,580
ank	57	2,035	1,961	Union	177	2,261	3,104
Brady	62	1,228	1,233	Clarendon	180	1,279	1,092
be	64	3,589	4,614	Warren	181	4,332	8,043
ville	65	3,126	3,386	Corry	195	5,677	5,369
	72	1,968	2,347	Busti, N. Y	205	.....	.....
r	76	1,317	1,070	Jamestown, N. Y	210	16,038	22,892
Bethlehem	77	1,026	1,269	Randolph, N. Y	212	1,201	1,209
na	78	1,963	4,142	Salamanca, N. Y	222	3,692	4,251
nton	82	1,126	1,190	Mayville, N. Y	227	1,164	943
sutawney	85	2,792	4,375	Bradford	240	10,514	15,029
Conemaugh	92	1,185	2,175	Olean, N. Y	241	7,358	9,462
tville	98	2,478	2,472	Cuba, N. Y	256	1,386	1,502
Fork	99	1,295	2,635	Franklinville, N. Y	258	1,021	1,360
n	100	2,164	2,004	Eldred	263	1,050	963
burg	112	1,202	1,574	Port Allegany	266	1,230	1,853
oldsville	112	2,789	3,435	Smethport	267	1,150	1,704
din	116	6,221	7,317	Coudersport	282	1,530	3,217
ois	121	6,149	9,375				
ty	125	10,932	13,264				
vay	140	1,903	3,515				

POLLUTION.

pection of the above table will show that although a great
rity of the municipalities are small, and probably do not con-
te a large amount of sewage or manufacturing wastes to the
, there are, nevertheless, many places that are probably sewered
that naturally pour their wastes into the river. There is no

record of any examination of the water of the Allegheny River e
those made by the filtration commission of the city of Pittsburg

The question of pollution has been considered in a report ma
Prof. William T. Sedgwick to the Pittsburg commission, the c
sions of which were that the water is polluted to a degree which
it unfit for use as a source of public supply in its raw state.
opinion is borne out by recent use of the water in Pittsburg.
records show that the typhoid fever rate is abnormal. Accord
the city of Pittsburg has investigated, and is even now prepar
introduce a system of filters, the total cost of which will not
from $3,500,000, while the expense of maintenance is calculated
report of Mr. Allen Hazen, consulting engineer, to be about $2
annually. This gives no idea of the damage done to the city of
burg alone by sewage pollution. In a well-considered article
lished in the Pittsburg Dispatch April 21, 1902, it was estimate
the cost of treating typhoid fever and the value of the lives los
that disease in the city of Pittsburg during the previous three
amounted to about $3,335,000, sufficient to pay interest upo
retire a bonded indebtedness of $13,000,000. These figures
charged to the account of typhoid fever alone, no estimate
made of the sickness and deaths arising from or induced by
water-borne diseases.

CHARACTER OF WATER.

Experiments were conducted during the years 1897–98, und
authority of the filtration commission, and throughout this
weekly chemical examinations were made of the water in the
gheny River. These results are almost the only available ones
show the character of the water; and as the samples were ta
short distance above the city of Pittsburg, they show clearly
is being contributed to the Ohio system by this branch.

TABLE 83.—*Analyses of water of Allegheny River at Brilliant, above Pit*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardnes	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hard-
1897.										
June	Decided		0.137	0.006	0.000	0.175	24.0	141		
July	do		.347	.034	.001	.106	31.3	269	60.8	
August	Slight		.210	.023	.000	1.050	20.3	90	40.5	13
September	do	3.7	.133	.019	.000	.650	27.0	131	46.3	4
October	do	2.3	.120	.017	.000	.550	38.1	177	50.9	4
ember	do	2.9	.152	.019	.000	.700	31.5	197	35.1	3
mber	do	3.0	.111	.015	.000	1.075	21.1	235	17.2	

TABLE 83.—*Analyses of water of Allegheny River at Brilliant, etc.*—Continued.

Date of collection.	Turbidity.	Color.	Nitrogen as				Chlorine.	Hardness.			Iron.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		Total residue.	Alkalinity.	Normal hardness.	
1898.											
January	Slight	2.8	.074	.016	.000	.885	15.3	153	14.8	6.1	1.12
February	do	2.1	.090	.020	.000	1.425	14.6	119	17.3	8.6	.59
March	Muddy	2.4	.076	.015	.000	.487	12.9	140	17.5	9.7	.40
April	Slight	2.2	.077	.018	.000	.458	13.6	94	18.3	4.6	.41
May	Decided	3.0	.164	.015	.000	1.80	16.6	207	21.3	6.7	.33
June	76	2.5	.085	.019	.000	.355	24.2	191	31.0	4.0	.10
July	361	2.7	.100	.027	.000	.694	24.7	131	34.1	11.7	.30
August	105	3.1	.130	.214	.000	.435	24.2	195	31.5	8.4	.20

A mineral analysis made of the samples from the river collected September, 1898, gave the following results:

TABLE 84.—*Mineral analysis of water from Allegheny River.*

[Parts per million.]

Total solids	127.0
Loss on ignition	43.0
Calcium oxide	20.4
Magnesium oxide	4.9
Sulphuric acid	16.1
Chlorine	22.0
Silica	1.0
Iron oxide	.1

The analyses set forth in Table 83 certainly do not necessarily indicate a water of dangerous qualities. Albuminoid and free ammonia and nitrites are low, and on the whole the analyses present an extremely favorable appearance. This, then, is one of the cases in which, as stated in the introduction to this work, little can be determined concerning the dangerous qualities of a river from chemical examinations alone. Inspection of the map shows that the centers of contamination above Pittsburg on the Allegheny River are far removed from that city, and the distances intervening seem sufficient to bring about all the purification apparent in the result of the analyses above set forth; yet, as pointed out by Professor Sedgwick in the report already referred to, the velocity of the Allegheny is high, being at times from 7 to 8 miles an hour. Under such circumstances pollution poured into the river at Oil City, for instance, would reach Pittsburg with fifteen hours, and at a slower rate of flow would certainly arrive within a few days, at least. Now, it can be easily understood that although organic matter may be oxidized and diluted to such an extent that *it would appear* in an analysis in small proportion only, *germs of disease entering* the river with such pollution could arrive

at the Pittsburg water "intake" in a virulent condition. Undoubtedly such has been the case during all the years in which Pittsburg has suffered abnormal typhoid-fever morbidity.

Coincident with the examinations above described, other points along the Allegheny were made use of for the collection of samples. A series was collected at Montrose, the intake for the water supply of the city of Allegheny, 4 miles above Brilliant, at Pittsburg. Another series was taken at Hulton, where the intake for the supply of Oakmont and Verona is situated, 6 miles above Brilliant, and a third at Wildwood, 1⅛ miles above Brilliant, whence the water is taken to supply Wilkinsburg and the First Ward of the city of Pittsburg. These examinations, however, did not show that the water was materially different from that at Brilliant, and, indeed, when the rapid flow of the river is taken into account, this might have been expected. There were, however, a number of examinations of samples of water taken at Etna, 2 miles below Brilliant, on the opposite side of the Allegheny, below a point where a certain amount of pollution is received from Pittsburg, and another series of examinations of samples taken at Millvale, 4 miles below Brilliant, also on the opposite side of the river. The average of these examinations for each point is given in Table 85. It will be seen that these do not differ materially from the samples taken at Brilliant, even though the water is undoubtedly contaminated by the addition of Pittsburg and Allegheny sewage. The reasons for this will be discussed presently.

TABLE 85.—*Analyses of water from Allegheny River at Etna and Millvale.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.	Number of samples.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal.		
Etna	2.9	0.119	0.030	0.000	0.682	18.6	155	32.7	5.6	0.70	35
Millvale	3.1	.149	.045	0.000	.706	25.8	147	47.0	8.5	.38	16

MONONGAHELA RIVER.

Drainage basin.—Monongahela River, which joins the Allegheny at Pittsburg to form the Ohio, has a drainage area of 7,625 miles. (See fig. 14.) It rises in the northern part of West Virginia and flows in a northerly direction, draining a part of the western slope of the Allegheny Mountains, most of which has a rugged character and lacks fertility. The region, once heavily timbered, has been very thoroughly cleared, except at the headwaters of the streams. The lower reaches of the river are fertile and yield a large crop of corn, but the country seems to be especially adapted to grazing.

Flow.—The flow of the Monongahela has not been determined in a manner more satisfactory than that of the Allegheny. In the year 1838 the flow of the Monongahela at Brownsville, 50 miles above Pittsburg, was reported to be only about 230 second-feet. This, however, was in a dry season. The lower reaches of the river constitute a "slackwater" basin, with a flow of not more than 1 foot per minute.

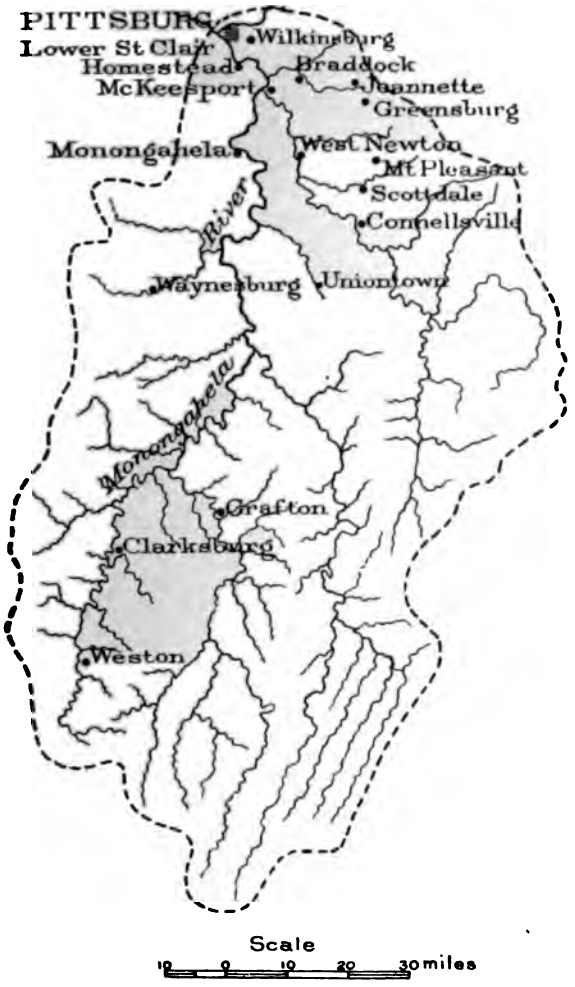


FIG. 14.—Monongahela River drainage basin.

Population of basin.—The population in the Monongahela Basin is denser than in the Allegheny, and there are larger cities, such as McKeesport, Homestead, Braddock, and Wilkinsburg, which are situated well down toward the mouth of the river. Therefore, the water which arrives at Pittsburg contains more recent pollution than that in the Allegheny. The important difference, however, lies in the fact that the flow of the Monongahela, as has been said, is slow, and there is the opportunity for sedimentation that arises in quiescent water.

TABLE 86.—*Cities and towns on Monongahela River and tributaries above Pittsburg.*

Place.	Distance in miles.	Population.	
		1890.	1900.
Lower St. Clair	3	3,680	4,638
Homestead	6	7,911	12,554
Braddock	9	8,561	15,654
Wilkinsburg	9	4,662	11,886
Port Perry	11	1,031	1,267
Turtle Creek	12	.....	3,268
Wilmerding	13	419	4,179
McKeesport	14	20,741	34,227
Elizabeth	20	1,804	1,866
Irwin	23	2,428	2,453
Jeannette	29	3,295	5,865
Monongahela	29	4,096	5,173
West Newton	32	2,285	2,467
Greensburg	33	4,202	6,508
Belle Vernon	41	1,147	1,901
Everson	50	.....	.....
Scottdale	52	2,693	4,261
Brownsville	52	1,471	1,553
Bridgeport	55	1,030	1,805
Mount Pleasant	57	3,652	4,745
New Haven	57	1,221	1,532
Connellsville	57	5,629	7,160
Dunbar	61	1,381	1,662
Uniontown	69	6,359	7,344
Waynesburg	80	2,101	2,544
Fairchance	95	1,092	1,219
Morgantown, W. Va	95	1,011	1,895
Somerset	112	1,713	1,834
Meyersdale	112	1,847	3,024
Fairmont, W. Va	120	1,023	5,655
Grafton, W. Va	140	3,159	5,650
Clarksburg, W. Va	150	3,008	4,050
Weston, W. Va	180	2,143	2,560
Buckhannon, W. Va	180	1,403	1,589

Character of water.—The increase of population, amounting to 75 per cent, as shown by the table presented above, is sure to bring about a proportional increase in pollution. It is not necessary to examine the water chemically or bacteriologically to prove that it is

for use as a water supply. McKeesport, with a population of ; Braddock, with 15,654; Homestead and Wilkinsburg, each fol- g closely in the number of inhabitants, empty raw sewage into lonongahela or its branches, and this must necessarily produce lition which is a detriment not only to the water itself, but to alty values along the river.

re are available a few analyses of the water of the Monongahela me of the branches, which were made at Pittsburg at the same time se already presented upon the Allegheny. A series of chemical inations made of the water of Indian Creek and other creeks in inity give a good idea of the character of the normal water of ection of the country, for the population on Indian Creek drain- rea is small, is not at any point provided with sewerage, and is iently well scattered to keep the water in its normal state, or y so.

TABLE 87.—*Analyses of water from Indian Creek and vicinity.*

[Parts per million.]

of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.			Average of how many samples.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	Iron.	
Creek	1.5	0.101	0.028	0.000	0.480	4.9	112	20.0	0.4	0.34	12
n	2.1	.128	.027	.000	.532	4.5	258	20.3	.5	.09	14
Hill Creek	1.7	.065	.030	.000	.675	3.9	35	20.7	.5	.01	3
nan River	1.7	.089	.055	.000	.750	4.6	84	15.3	5.3	.01	3
ogheny River	1.5	.128	.062	.000	.975	3.5	40	17.6	.4	.01	2

ming down to Pittsburg again, we find a series of analyses made e water just above the city.

ABLE 88.—*Analyses of water from Monongahela River at Pittsburg.*

[Parts per million.]

collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.			
		Albuminoid ammonia	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	Iron.	
897.											
		0.136	0.081	0.000	0.740	13.5	154				
		.186	.076	.001	.768	4.3	141	28.5	21.2	1.95	
t	1.0	.173	.100	.001	1.121	10.7	129	19.5	37.8	1.93	
nber	2.6	.130	.119	.000	.979	9.5	145	16.4	41.5	.30	
er	1.2	.403	.142	.000	1.261	15.5	285	9.0	55.2	.15	
nber	1.9	.194	.145	.000	.825	14.7	265	14.1	48.4	1.33	
nber	2.5	.166	.030	.000	1.275	13.1	328	14.3	17.2	2.72	

TABLE 88.—*Analyses of water from Monongahela River, etc.*—Continued.

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.										
January	2.1	.095	.030	.000	1.245	9.1	298	13.8	15.2	2.0
February	2.0	.177	.021	.000	1.500	11.1	219	13.2	22.4	1.2
March	2.0	.080	.025	.000	.425	9.2	203	10.4	39.9	.2
April	2.1	.097	.018	.000	.450	8.2	127	11.5	12.0	.1
May	2.8	.125	.026	.000	.375	12.1	167	14.6	25.9	.1
June	2.1	.105	.096	.000	.375	14.2	155	11.2	21.5	.0
July	2.2	.126	.041	.000	.825	14.2	170	12.8	33.6	.0
August	3.0	.190	.050	.000	.375	5.2	292	16.2	3.2	.0

Although, as has been stated, the sewage pollution of the Monongahela is more extensive near that city than in the Allegheny, it will be seen by comparison of Tables 83 and 88 that the Monongahela contains a smaller amount of organic matter than the Allegheny. The reason for this well illustrates what has already been said concerning the water of the Ohio Basin. The normal content of organic matter is so high that under ordinary circumstances the organic matter which is added to the river by the disposal of sewage therein does not increase the total amount to a significant degree. In other words, the amount of organic matter in the Ohio Basin is insignificant from the standpoint of sewage pollution, because of the fact that the unpolluted water often carries a larger amount of organic matter than the sewage brought into it. The two rivers under discussion well illustrate this point. We have in the Allegheny a "quick-spilling" basin, out of which is carried at times enormous amounts of sediment, consisting in a large measure of organic matter. The river flows swiftly, and there is little or no opportunity for sedimentation, so that when the water reaches Pittsburg its condition is not greatly improved nor changed.

In the Monongahela, on the other hand, we have a slack-water basin. Large amounts of silt are poured into it from the tributaries, as large as or larger than the amounts brought into the Allegheny. Yet because of the fact that there is ample opportunity in the slack water of the main river for subsidence, the water appears better upon chemical examination at Pittsburg in spite of the fact that comparatively large amounts of sewage are poured into the Monongahela only a short distance above. These facts illustrate excellently the point *just enunciated*; namely, that under ordinary circumstances the *amount of* organic matter emptied from sewers into the Ohio Basin

small in comparison with that which is brought into the river from atural sources.

This consideration brings up the question of the value of determinations of organic matter in water, and seems to indicate that uch determinations are of little aid in an investigation of this nature, f they are not indeed entirely useless. At all events, one should be ery careful in regard to his premises before attempting to draw conlusions from determinations of organic matter.

MAHONING RIVER.

NATURAL RESOURCES.

Drainage area.—The area of the Ohio Basin next below the confluence of the Allegheny and the Monongahela rivers in which investigations have been made, the results of which have been published, is that of Mahoning River. This river drains 1,300 square miles in the eastern part of Ohio, being bounded on the north by the Lake Erie divide and on the south by the Muskingum and several other small streams, which enter the Ohio direct (see fig. 15).

The Mahoning rises in Columbiana County, Ohio, flows through the northeast corner of Stark County, and then by a circuitous course enters Portage, Trumbull, and Mahoning counties, flowing first in a northeasterly and then in a southeasterly direction, crossing the Ohio line and emptying into Beaver River in Pennsylvania, 8 miles from the Ohio boundary. Beaver River in turn enters the Ohio 40 miles below Pittsburg.

The basin of the Mahoning is rolling in some portions, while in others it is decidedly flat. It is rich in minerals and is extremely fertile. The valley is an important manufacturing place and is well supplied with transportation facilities. Under such favorable circumstances the population is rapidly increasing and the country is uncommonly prosperous.

Power.—The Mahoning is one of the best power streams in the Ohio Basin, and has been developed to an unusual extent as compared with other streams in this part of the country. Prof. Dwight Porter states that in the year 1880[a] 36 mills were situated upon the river, utilizing a total fall of 442½ feet, developing a horsepower of 1,146. It is probable that numerous changes have been made since that time in conformity with the decline of Ohio power values, and the figures are not applicable at the present date. The power developed is applied almost entirely to the grist and lumber business.

Flow.—There appear to be no satisfactory gagings of the flow of the river. In the report of the Ohio State Board of Health for 1898 there are given the results of a few measurements covering a period

[a] Tenth Census, vol. 17, pt. 2, p. 465.

of five months during a very dry season, but, as explained in t report, the gagings were attended by unfortunate circumstan which almost entirely vitiate their value, and they were not in a event continued for a sufficient period to indicate the normal flo

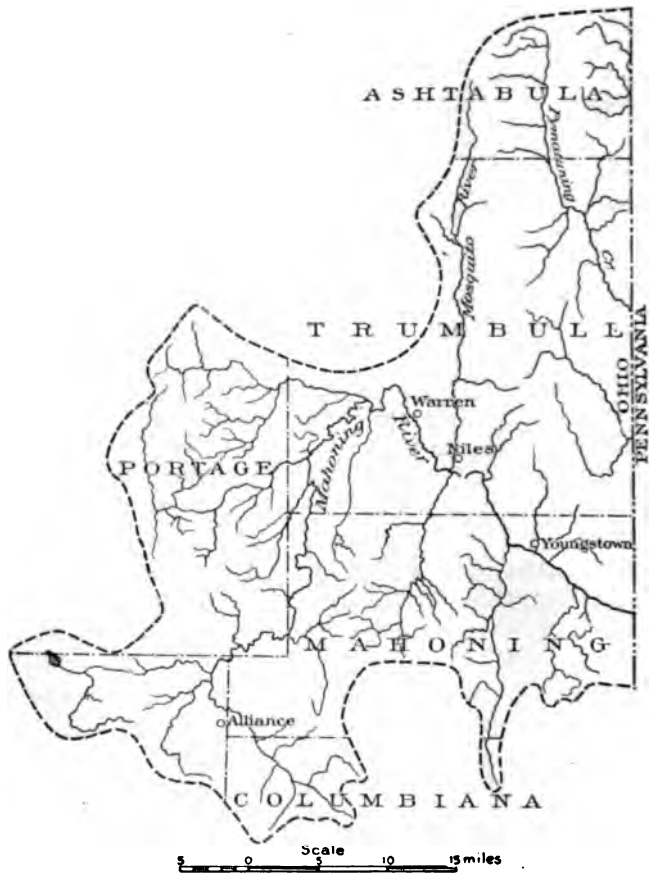


FIG. 15.—Mahoning River drainage basin.

the stream. The common observation is that the river fluctu widely and is subject to freshets.

CHARACTER OF WATER.

No records of examinations of unpolluted water in the Mahon Basin have been found. The excellent work of the State Boar Health was confined to districts undoubtedly polluted and theref gives no idea of the character of the normal water in this basin. is probable that the unpolluted surface water in the Mahoning Ba does not differ widely in character from that indicated by the analy of the water of the river above Alliance, which will be shown below

Alliance is a city of 8,974 inhabitants (census of 1900), and is si

in the upper part of the Mahoning Basin. Therefore it is the of the extensive pollution for that basin. Above Alliance the iage area comprises 73 square miles, and the population is not rom 60 per square mile. There are no mills nor factories on the , and the country is largely devoted to manufacturing and dairy-

There are six small villages on the river, the largest having ably no more than 300 inhabitants. Under some circumstances erous pollution might arise at two, North Georgetown and Damas-

Two miles above Alliance is situated the Fairmont Children's e, which shelters about 200 persons, and pours raw sewage into river. Under such circumstances when the water reaches the ce of the Alliance Waterworks it is generally in an acceptable ition, but is subject to the dangers above noted. The intake is down toward the center of the city, so that there is undoubtedly tain amount of contamination from Alliance itself.

TABLE 89.—*Analyses of water from Mahoning River above Alliance.*

[Parts per million.]

f collec-on.	Turbidity.	Color.	Nitrogen as-				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
97.										
19	None	4.5	0.528	0.136	0.012	0.23	1.5	240	110	36
24	Slight	7.0	.478	.126	.010	.28	.2	175	70	38
2	Distinct	4.0	.390	.094	.005	.07	2.3	400	136	54
29	None	1.5	.136	.059	.003	.00	3.0	415	182	58
7	Very slight	2.0	.150	.060	.000	.00	3.2	410	204	54
26	Decided	10.0	.592	.114	.007	6.5	2.3	470	78	64
verage			.379	.100	.006	.21	2.1	350	130	51

uring the periods covered by the above table the rainfall at Akron, nearest weather observation station, was as follows:

TABLE 90.—*Rainfall at Akron, Ohio.*

	June.	July.	August.	September.	October.	November.	Whole period.
l fall	1.55	5.06	2.90	1.07	1.65	4.85	17.16
ation	−2.81	+1.20	.35	2.12	.77	+1.69	− 3.16

he city of Alliance is provided with a system of water supply, and consumption approaches 5,000,000,000 gallons daily. The sewer-

age system introduced in 1896 has been well extended, and in year 1898 poured into the chemical precipitation works 300,000 gall of sewage daily. The purification works do not seem to be extrem efficient, if we may judge from the analyses and bacteriological exa nations made by the Ohio State Board of Health. The report of bacteriologist in the year 1898 makes the following statement w reference to the Alliance sewage disposal:

At this town there is in operation sewage-disposal works which take car the sewage by chemical precipitation. Examinations made at the works th selves showed that so far from this method destroying bacteria or lessening number, the effluent from the works which discharged into the river was m times richer in bacteria than the original sewage, though the curve in gen runs parallel with the curve above the station.

TABLE 91.—*Analyses of water from Mahoning River below Alliance.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hard-
1897.										
June 19	None	3.0	0.422	0.200	0.022	0.07	3.0	310	128	
July 24	Slight	8.0	.520	.196	.020	.33	.2	165	56	
Sept. 2	do	3.0	.422	.122	.015	.12	4.8	410	138	
Sept. 29	None	2.0	.366	.473	.035	.....	9.0	415	170	
Oct. 27	do	4.0	.356	2.100	.055	.03	15.5	480	216	
Nov. 26	Decided	5.0	.390	.176	.022	.54	4.5	380	102	
Average			.412	.544	.028	.18	6.2	358	135	

The next important center of population below Alliance is Warr in Trumbull County, which in 1900 had 8,529 inhabitants. The a of the watershed above Warren is not far from 600 miles, and t density of the rural population is about 45 per square mile. Betwe Alliance and Warren there are a large number of small country v lages, having a population of 3,500 or 4,000, the most important bei Newton Falls and Leavittsburg. At both of these places danger pollution may be expected, as well as from the Trumbull Cou Infirmary, which contributes a certain amount of sewage above t intake of the Warren waterworks. The river receives contaminati from these three points, from Alliance, and from the storm sewers Warren, which enter the river just above the waterworks.

TABLE 92.—*Analyses of water from Mahoning River above Warren.*

[Parts per million.]

of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
97.										
18	None	0.3	0.370	0.062	0.002	0.09	2.0	190	92	16
23	Decided	12.0	.606	.156	.010	.23	.3	130	36	22
28	Very slight	3.0	.336	.062	.000	..	3.5	245	100	28
30	do	1.5	.180	.036	.005	.00	4.2	275	124	32
8	Slight	3.0	.158	.018	.000	.00	3.7	235	140	14
27	Decided	7.0	.440	.074	.009	.85	3.3	205	54	46
rage		3.0	.348	.068	.004	.20	2.8	213	91	26

addition to this the industrial pollution is extensive. Within the are situated numerous works, such as a rolling mill, tube works, inseed-oil, flour, and paint mills, as well as a galvanizing plant, which large quantities of waste acid are turned into the river.

TABLE 93.—*Analyses of water from the Mahoning River below Warren.*

[Parts per million.]

of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
24	Decided	10.0	0.552	0.204	0.010	0.28	2.1	170	40	36
28	Very slight	3.5	.430	.096	.001	.06	4.5	235	90	26
30	do	1.5	.194	.070	.005	.00	8.7	275	126	18
8	Slight	3.0	.304	.102	.017	.13	42.5	335	136	30
27	Distinct	8.0	.454	.098	.017	.86	5.0	270	56	56
rage		5.2	.387	.114	.011	.27	12.6	257	90	33

ie next important place on Mahoning River below Warren is s, which has a population or 7,468. Between Warren and Niles e is little pollution of a dangerous character, and the water which hes the latter place is not materially different from that shown in le 93. At Niles, although there is no complete system of sewers, *ollution is extensive* and dangerous. There are probably about

50 house connections, with short lines of pipe; but in addition to the there are works which contribute waste, notably a tin-plate and iro galvanizing plant, which discharge chemicals, mostly of an aci nature, into the river. During the summer of 1897 the river was dis colored for 9 miles below Niles and many fish were killed. In additio to this the outhouses connected with the industrial plants are situate upon the edge of the stream, as is also that of a large schoolhouse. The pollution is therefore constant and dangerous, especially in vie of the fact that this place is only about 10 miles above the intake o the Youngstown waterworks.

Analyses were made of water taken from the river below Niles, and a comparison of the results with those of analyses of water take below Warren shows increased pollution. As will be noted by com parisons of Tables 93 and 94, the increase in chlorine is enormou This, however, is not due entirely to sewage pollution, but arises fro the influx of water from several salt springs in the vicinity of Nile

TABLE 94.—*Analyses of water from Mahoning River below Niles.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1898.										
June 18		3.5	0.392	0.126	0.007	0.05	4.0	200	102	2
July 23	Decided	12.0	.620	.144	.010	.25	.3	135	34	1
Aug. 28	Slight	3.0	.328	.130	.005	.01	4.5	255	100	2
Sept. 30	None	2.0	.208	.078	.004	.00	4.5	245	124	1
Oct. 28	Slight	3.0	.268	.244	.001	.06	6.2	250	140	8
Nov. 27	Decided	10.0	.516	.096	.009	.88	3.3	233	54	4
Average		5.5	.389	.136	.008	.21	3.8	220	92	9

The next important center of population below Niles is Youngstown, the largest city on Mahoning River, containing 44,885 inhabitants. The area of the Mahoning Basin above Youngstown is approximately 900 miles, about 50 per cent of the population of which is urban. Between Niles and the water-supply intake at Youngstown the principal points are Cortland, Mineral Ridge, Canfield, Mahoning City Infirmary, Girard, Columbiana, and a part of the city of Youngstown itself, containing approximately nearly 10,000 persons. These represent a total population of 16,352.

The pollution from these centers is not extensive, and only that *from the* upper end of Youngstown may be termed dangerous. The

ality of water as it arrives at the Youngstown intake is therefore perior to that which leaves Niles.

TABLE 95.—*Analyses of water from Mahoning River above Youngstown.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—					Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.		Alkalinity.	Normal hardness.
1897.										
une 18	None	5.0	0.424	0.094	0.001	0.05	5.3	245	90	28
uly 23	Decided	25.0	.716	.120	.005	.18	.3	145	22	20
ug. 28	Very slight		.436	.112	.003	.07	4.0	200	56	24
ept. 30	None	1.5	.192	.056	.004	Tr.	13.5	370	88	86
ct. 28	do	3.0	.194	.052	.004	.04	15.2	380	106	60
ov. 27	Distinct	20.0	.386	.096	.009	.46	5.0	255	64	54
Average		10.8	.391	.088	.004	.13	7.2	266	71	46

For some miles the Mahoning River flows through Youngstown. The city is provided with intercepting sewers, which carry all sewage below the water intake and discharge it into the river direct. After the addition of this sewage the water has the character shown in the following table.

TABLE 96.—*Analyses of water from Mahoning River below Youngstown.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—					Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.		Alkalinity.	Normal hardness.
1897.										
une 18	None	4.0	0.436	0.166	0.015	0.10	7.0	225	96	28
uly 23	Decided	25.0	.908	.120	.010	.31	.5	220	26	38
ug. 28	Very slight	8.5	.456	.218	.015	.27	6.5	215	64	28
ept. 30	None	2.0	.268	.230	.030	.18	18.0	390	114	70
ct. 28	do	5.0	.454	.750	.092	.27	25.2	405	130	78
ov. 27	Distinct	20.0	.460	.150	.017	.56	5.7	283	52	58
Average		10.5	.497	.272	.030	.28	10.5	286	80	50

of water taken from Black Fork above Shelby, which is reprodu below.

TABLE 97.—*Analyses of water from Black Fork above Shelby.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Precipitation
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1899.											In
May 3	18	w[a]	0.166	0.071	0.008	0.06	4.1	406	197.6	33	—
May 29	28	e	.660	.110	.002	.11	Tr.	956	120.8	13.9	...
June 27	25	v	.174	.070	.002	.10	1.5	354	176.8	33.8	+
July 18	30	e	.268	.061	.016	.06	.9	407	153.6	84.8	+
Aug. 17	20	v	.246	.088	Tr.	.02	4.3	428	191.6	81.6	
Sept. 18	16	v	.166	.053	Tr.	.03	2.1	411	191.4	59.2	+
Oct. 12	25	None.	.146	.033	Tr.	.00	1.3	414	227.4	48.2	+
Nov. 17	45	e	.132	.018	.004	.02	1.7	468	181.8	98.6	—
Average.	26	.....	.245	.063	.004	.05	2.0	480	180.1	56.6	...

[a] w, woody; e, earthy; v, vegetable.

The results above reported indicate that the water analyzed c tained considerable organic matter, which, if we may judge from conditions existing in the contributing drainage area, is of vegeta origin. The water is not highly colored and there is no indica that pollution exists other than that inevitably arising from deca vegetation. The free ammonia, nitrites, and chlorine are low; water contains a comparatively large proportion of alkaline sa which cause a high degree of hardness. It is evident, however, t nearly 75 per cent of these salts are carbonates. In general, the se of analyses is important because it is one of a very few availa reports upon a normal or practically normal surface water in northern drainage basin of the Ohio River.

For purposes of comparison, analyses of water from Black F below Shelby were made by the State Board of Health, the samp being collected at the same time as were those reported in Table

BLACK FORK.

e head of Black Fork the basin is a sparsely settled agricul-egion, containing only four small hamlets, the largest having ore than 150 inhabitants. Shelby, a growing manufacturing aving a population of 4,685, is the highest point of appreciable

FIG. 16.—Muskingum River drainage basin.

tion. The run-off water from the area above this place is prob-nearly normal.

e Ohio State Board of Health has made a faithful survey of asin, and a series of chemical examinations was made during spring, summer, and fall of the year 1899. In the published *t of this work* there appears a series of analyses of samples

of water taken from Black Fork above Shelby, which is reproduced below.

TABLE 97.—*Analyses of water from Black Fork above Shelby.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Precipitation, departure from normal for month.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1899.											*Inches.*
May 3	18	w[a]	0.166	0.071	0.008	0.06	4.1	406	197.6	33	−2.15
May 29	28	e	.660	.110	.002	.11	Tr.	956	120.8	13.9	.....
June 27	25	v	.174	.070	.002	.10	1.5	354	176.8	33.8	+ .44
July 18	30	e	.268	.061	.016	.06	.9	407	153.6	84.8	+ .29
Aug. 17	20	v	.246	.088	Tr.	.02	4.3	428	191.6	81.6	2.21
Sept. 18	16	v	.166	.053	Tr.	.03	2.1	411	191.4	59.2	+1.31
Oct. 12	25	None.	.146	.033	Tr.	.00	1.3	414	227.4	48.2	+ .06
Nov. 17	45	e	.132	.018	.004	.02	1.7	468	181.8	98.6	−1.62
Average.	26	.....	.245	.063	.004	.05	2.0	480	180.1	56.6	.....

[a] w, woody; e, earthy; v, vegetable.

The results above reported indicate that the water analyzed contained considerable organic matter, which, if we may judge from the conditions existing in the contributing drainage area, is of vegetable origin. The water is not highly colored and there is no indication that pollution exists other than that inevitably arising from decayed vegetation. The free ammonia, nitrites, and chlorine are low; the water contains a comparatively large proportion of alkaline salts, which cause a high degree of hardness. It is evident, however, that nearly 75 per cent of these salts are carbonates. In general, the series of analyses is important because it is one of a very few available reports upon a normal or practically normal surface water in the northern drainage basin of the Ohio River.

For purposes of comparison, analyses of water from Black Fork below Shelby were made by the State Board of Health, the samples being collected at the same time as were those reported in Table 97.

TABLE 98.—*Analyses of water from Black Fork below Shelby.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—			Chlorine.	Total residue.	Hardness.		Precipitation, departure from normal for month.
			Albuminoid ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.										*Inches.*
May 3	12	d [a]	0.238	0.015	0.06	11.7	538	115.8	100.9	−2.15
May 29	32	e	.530	.032	.15	7.8	435	103.0	54.1	.....
June 27	17	d	.198	.034	.12	12.5	473	137.8	87.0	+ .44
July 18	60	v	.352	.022	1.25	6.3	383	110.2	88.8	+ .29
Aug. 17	20	v	.236	Tr.	.05	28.3	810	57.2	327.6	−2.21
Sept. 18	20	Cattle	.442	.002	.06	32.1	959	90.4	350.6	+ 1.31
Oct. 12 [b]	----	----	----	----	----	----	----	----	----	+ 0.06
Nov. 17	20	m	.100	.014	.06	8.7	598	77.4	225.6	− 1.62
Average	26	.....	.299	.017	.25	15.3	599	98.8	176.4	.....

[a] d, disagreeable; e, earthy; v, vegetable; m, moldy. [b] No water flowing.

The effect of pollution from Shelby is evident in the analyses above reported. There is a significant rise in the proportions of free ammonia, nitrites, and chlorine, which can be due to nothing else than sewage pollution. It is worthy of note that there is a great change in the character of the alkaline salts contained in the water. The marked decrease in alkalinity, accompanied by the increase in normal hardness, shows that through some influence, probably by the discharge of some chemical at Shelby, the carbonates have been changed to sulphates or chlorides.

Black Fork is joined by Rocky Fork about 30 miles below Shelby, but the intervening country is sparcely settled and there is little further material pollution except that from Richmond County Infirmary.

ROCKY FORK.

The drainage area of Rocky Fork lies in the central part of Richland County, immediately south of that of Black Fork. During past years it has been one of the most grossly polluted streams in Ohio, because of the discharge into it of raw sewage from Mansfield, a city of 17,640 inhabitants. The condition of the stream below this city has been so offensive that it became necessary to establish a system of sewage disposal. The Ohio State Board of Health examined, previous to the installation of this disposal plant, two series of samples of water from Rocky Fork, one of the sampling points being located

above the city and the other below. That part of the drainage area above Mansfield comprises a country richly fertilized for agricultural purposes, and the run-off is therefore not normal for the basin.

TABLE 99.—*Averages of analyses of water from Rocky Fork, above and below Mansfield.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Mansfield	20	....	0.282	0.051	0.005	0.08	2.9	512	169.7	59.0	8
Below Mansfield	23	f[a]	.413	.088	.088	.14	16.7	583	146.1	55.5	8

[a] f, fishy.

It is hardly necessary to comment on the contrast offered by the two averages set forth in the above table. The second statement shows an enormous increase in organic matter, in chlorine, and in all other constituents which serve to indicate extensive sewage pollution. It is believed that the river has been improved since the establishment of the Mansfield sewage purification works, but an analytical proof is not at hand.

Between the junction of Rocky Fork and Black Fork and the entrance of Clear Fork is the village of Loudensville, containing 1,500 inhabitants. There is no public water supply or sewerage system, but there is nevertheless considerable drainage into the stream by private sewers, ditches, and gutters.

Clear Fork appears to be a comparatively clean stream, the principal center of population within its drainage area being Belmont, which has a population of 1,039.

JEROME FORK.

At the confluence of Black and Jerome forks is the head of Mohican River. Jerome Fork drains the greater part of Ashland County and the western portion of Wayne County. The only place of importance upon the stream is the city of Ashland, with 4,087 inhabitants, provided with a water supply and sewerage system.

MOHICAN RIVER.

From the above statements, it is clear that the water contributed to Mohican River by the tributaries described is badly polluted and of little value in its raw state as a water supply. The remainder of

he resources vested in the water of this stream are probably not reatly affected by pollution.

OWL CREEK.

Mohican River flows nearly due south to its confluence with Owl Creek, and there are upon its banks no important centers of population. The water flowing in the channel must, therefore, constantly improve in quality. Owl Creek, however, is a different stream; it drains the greater part of Knox County, and extends to the Scioto River divide. The country is level and is a very fertile agricultural region. In the middle of the drainage area is the city of Mount Vernon, having a population of 6,633. It is a rather important manufacturing town, although it has not grown much during the last decade. A water supply and a system of sewerage has been provided, the latter emptying directly into Owl Creek. There is also considerable surface pollution from vaults and cesspools. Above the city of Mount Vernon there are, in Owl Creek Basin, several small villages, which, together with the richly fertilized fields, contribute a sufficient amount of pollution to the river to materially change the quality of the water, which would otherwise be normal.

TABLE 100.—*Averages of analyses of water from Owl Creek above and below Mount Vernon.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Mount Vernon	13	O[a]	0.095	0.036	0.003	0.05	1.2	292	192.0	13.9	8
Below Mount Vernon	14	M	.121	.060	.009	.08	3.1	303	190.7	33.3	8

[a] O, oily; M, musty.

KILLBUCK CREEK.

Killbuck Creek enters Mohican River a short distance below the mouth of Owl Creek. It drains a large part of Wayne and Holmes counties and a small part of Coshocton County. At the headwaters of this stream is a comparatively large rural population, the principal centers of which are Warsaw and Creston, while the highest town of importance is Wooster, a city of 6,063 inhabitants.

Above Wooster two points were selected by the Ohio State Board of Health for the collection of samples of water for analysis; one in Killbuck Creek, above the mouth of Apple Creek, which flows in at Wooster; one in Apple Creek above Wooster, and the third below Wooster,

the latter representing a mixture of waters from both Killbuck a Apple creeks. Above Wooster on Apple Creek are the Wayne Coun Childrens' Home and the Wayne County Infirmary, which pollute t water of the stream to some extent. At Wooster are Wayne Colle and several industrial establishments.

TABLE 101.—*Averages of analyses of water from Apple and Killbuck creeks abo Wooster and from Killbuck Creek below Wooster.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of an
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Killbuck Creek above Wooster	28	M[a]	0.336	0.112	0.006	0.05	5.4	336	130.1	23.4	
Apple Creek above Wooster	19	None.	.153	.038	.003	.05	2.6	254	140.2	16.6	
Killbuck Creek below Wooster	28	M	.322	.165	.022	.09	6.5	359	130.5	28.3	

[a] M, musty.

Between Wooster and the junction of Killbuck Creek with W honding Creek there are numerous small villages, a few being p vided with small sewerage systems. It is more than likely that t condition of the water shown in the last analysis in Table 101 is mai tained by these small pollution points in practically the same con tion as that indicated in the table.

From the mouth of Killbuck Creek it is only a short distance do Walhonding Creek to Coshocton, the head of Muskingum Riv The Ohio State Board of Health has made an analysis of the water Walhonding Creek above Coshocton which shows clearly the ch acter of the water contributed to the Muskingum by the Walhondi Basin.

TUSCARAWAS RIVER.

The basin of the Tuscarawas covers about 2,547 square miles in t northwestern portion of Muskingum watershed. It is the larg tributary of the Muskingum, flowing through a fertile, prospero country, which has a large population, and is dotted over with rapid growing municipalities. In the central-southeastern part of the ba coal mining is largely developed, while agriculture is confined in g eral to the northern and western portions. The river rises in Su mit County, and, by a somewhat circuitous route, finally take course southwest, flowing through Stark, Tuscarawas, and Coshoc *counties,* and meets Walhonding Creek at Coshocton to form *Muskingum.*

The tributaries of the Tuscarawas are important, and cover diversified portions of the drainage area. Chief among these is Big Stillwater Creek, which flows from the south, through Harrison and Tuscarawas counties, draining an area of 472 square miles. Sugar Creek flows in from the northwest, its basin comprising 356 square miles. Sandy Creek is an important stream which flows in from the east, along the northern part of Carroll and the southern boundary of Stark counties.

HIGHLAND TRIBUTARIES.

Wolfe and Chippewa creeks drain the northernmost portions of the Tuscarawas Basin, comprising parts of Summit, Medina, and Wayne counties. There are numerous small villages in the basin, which have no important influence on the character of the run-off water, although they undoubtedly pollute it to some extent. The first important center of population is Barberton, a comparatively new town, the growth of which has been rapid, by reason of the recent establishment of manufacturing. A system of sewers has been provided, which serves about 3,000 people, and has an outlet in Wolfe Creek. The manufacturing refuse, too, damages the stream to some extent. Wadsworth, Orrville, Dalton, and Doyleston are situated in the drainage area. These municipalities are not important, although from Wadsworth there is considerable contamination of the stream from the salt works established there. Rillman is also an important center of the salt industry, the wastes from which impregnate the whole drainage from this section.

The largest city in the Tuscarawas Basin is Massillon, an important manufacturing place in Stark County, situated a few miles below the confluence of Wolfe and Chippewa creeks, and having a population of 11,944. Refuse from strawboard factories and other manufacturing plants, as well as the sewage from a combined system of sewers, pollutes the stream. The Ohio State Board of Health has made a series of analyses of the water taken from the river above and below Massillon, the average results of which are set forth in Table 102.

TABLE 102.—*Averages of analyses of water of Tuscarawas River above and below Masillon.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Hardness.			Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		Total residue.	Alkalinity.	Normal hardness.	
Above Massillon	23	v[a]	0.175	0.060	0.003	0.06	102.8	513	136.8	58.8	8
Below Massillon	29	M	.343	.093	.007	.10	64.5	578	152.0	33.6	8

[a] v, vegetable; M, musty.

In the above analyses the effects of waste from salt works are readily apparent in the high chlorine content. Aside from this, the river shows a high content of organic matter, which, although no records of normal water are available for comparison, seems to indicate pollution from the country above. The average representative analyses of water from the river below Massillon show a characteristic increase in the amount of organic matter, yet the chlorine does not appear to be present in so large proportion as above the city. This is not explained in the last report of the Ohio State Board of Health; it may be due to dilution, as there are two streams entering the river between the sampling point above the city and that below.

SANDY CREEK.

Sandy Creek enters the Tuscarawas a short distance below Massillon, and contributes a considerable amount of pollution from Canton, Wellsville, Minerva, and other small places. Minerva has a population of 1,200 and is situated upon Clear Fork, at the extreme eastern end of the Muskingum Basin.

NIMISHILLEN CREEK.

The principal stream of interest in the Sandy Creek drainage area is a tributary called Nimishillen Creek, which drains the country to the north, including the city of Canton and the village of Louisville. The latter is situated upon the east branch of the creek, has a population of 1,374, and is provided with a public water supply, but no sewers. The east branch runs through Canton and joins the west branch at the lower end of the city. The Ohio State Board of Health has conducted two series of analyses of water from west branch, one above and one below Canton.

TABLE 103.—*Averages of analyses of water from Nimishillen Creek above and below Canton.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Canton	28	23	v[a]	0.176	0.051	0.006	0.35	2.0	294	150.6	35.1	2,400	
Below Canton	70	28	M	.446	.741	.039	.30	10.4	343	151.7	50.2	95,000	

[a] v, vegetable; M, musty.

The contrast presented by the above averages indicates unmistakably the great change in the character of the water after it receives pollution from Canton.

TUSCARAWAS AT CANAL DOVER AND NEW PHILADELPHIA.

Canal Dover and New Philadelphia are cities situated on the opposite sides of Tuscarawas River at the junction of Sugar Creek, a stream which drains a considerable area of country to the northwest. The former city has a population of 5,422; the latter contains 6,213 inhabitants. Both are important manufacturing places, and their industrial plants contribute a large amount of foul matter to the river. Canal Dover has no sewerage system at present, but the drainage into the river is nevertheless extensive. New Philadelphia has an excellent sewerage system, which discharges into the river. We have, then, at this point a combined population of 11,635, the wastes from which have an important effect on the quality of the Tuscarawas River.

TABLE 104.—*Averages of analyses of water from Tuscarawas River above Canal Dover and below New Philadelphia.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Canal Dover	23	e[a]	0.227	0.062	0.005	0.07	23.9	369	112.8	39.3	8
Below New Philadelphia	24	e[a]	.237	.060	.005	.10	23.4	343	107.4	36.2	8

[a] e, earthy.

Comparison of the results of analyses from the two points above stated shows that the water in Tuscarawas River is not materially changed after receiving the pollution from Canal Dover and New Philadelphia. It is probable that the amounts of nitrogen and of chlorine are practically the same, and that the color, turbidity, and odor do not differ widely. The reason for this is not far to seek. Examination of the map will show that between the sampling point above Canal Dover and that below New Philadelphia three tributaries enter—Sugar Creek, Stone Creek, and Oldtown Creek. The first of these tributaries drains an area of 356 square miles; the other two have basins considerably smaller. The water flowing from these tributaries is not polluted to any significant extent, and it is reasonable to believe that the large measure of dilution, which must, of necessity, arise, is sufficient to account for the lack of material difference in the character of the water as shown by analyses at the two sampling

points. The quantitative determinations of bacteria made by the St Board of Health, however, tell another story. It has also been remark that the differences between gelatin culture media manufactured different laboratories are often the cause of varying results in det mining the number of bacteria, so that when the same water is test the number of bacteria found in different cases varies widel Therefore little value can be given to quantitative determinatio unless numbers vary to such an extent that the difference betwe one and the other is greater than any possible error introduced by t discrepancy in the work. In the report of the Ohio State Board Health, above referred to, the average number of bacteria per cub centimeter above Canal Dover is 2,350, and below New Philadelph 6,200, a difference so wide that it can not be reasonably accounted f by variations which might be introduced into the work by the use nonuniform culture media. The media used in these determinatio were all made in the same laboratory and, presumably, after the sam methods, so that it is probable that the above-described variatio would not occur. The fact that there are so many more bacteria i the water below New Philadelphia than above Canal Dover aris unquestionably from the difference in the character of the organic matter. In other words, the fact that there is sufficient organic matter of a certain kind in the water at the lower sampling station to provide food for 6,200 bacteria, while at the upper station it is suffi ient in amount to provide food for only 2,350, shows that the character of the organic matter has been seriously changed, even though the large degree of dilution arising from the cause above stated preserves the proportionate amounts practically the same.

STILLWATER CREEK.

After proceeding down Tuscarawas River for 5 or 6 miles one comes upon the confluence of Stillwater Creek. This stream has a drainage area of 472 square miles, lying principally in Harrison, Belmont and Tuscarawas counties. The river forks a few miles from this confluence with the Tuscarawas, and thereafter the northernmost branch is called Little Stillwater Creek, while that immediately to the south is known as Big Stillwater Creek. The pollution in the basin of Little Stillwater Creek is not extensive, while in the upper part of the Big Stillwater Basin there are only a few small centers of population, such as Barnesville, Piedmont, and Freeport. At the junction of the two forks are situated the municipalities of Uhrichsville and Dennison.

The following statement of averages of analyses of water above Uhrichsville and below Dennison are taken from the report of the Ohio State Board of Health, above referred to.

105.—*Averages of analyses of water from Stillwater Creek above Uhrichsville and below Uhrichsville and Dennison.*

Parts per million.

Place of collection.	Color	Odor	Nitrogen as— Albuminoid ammonia	Free ammonia	Nitrites	Nitrates	Chlorine	Total residue	Hardness as— Alkalinity	Normal hardness	Number of analyses made
Above Uhrichsville	25	M[1]	0.287	0.089	0.007	0.07	4.5	344	114.1	17.8	8
Below Uhrichsville and Dennison	25	M	.288	.188	.007	.17	7.1	376	98.8	40.2	8

[1] M. musty

he evidences of increase in pollution appearing in the two aver-s above referred to are easily appreciable, notably by the rise in ammonia and chlorine.

elow the mouth of Stillwater Creek, in the course of the 40 miles ch intervene between that point and the head of Muskingum er, small villages are situated upon the banks of the stream, con-ning the usual number of industries, but the only important center pollution is Newcomerstown, which has, according to the Twelfth nsus report, 2,659 inhabitants.

MUSKINGUM RIVER BELOW COSHOCTON.

Walhonding Creek and Tuscarawas River are further polluted at ir confluence by drainage from the city of Coshocton, which has a pulation of 6,473. Along the water front of this city are located portant manufacturing plants, which pour their wastes into the eam. The city is provided with a water supply and sewerage sys-m, and the sewage, together with that carried by surface drains, as ell as the town garbage, is poured into the river. There arises, erefore, at this point an important contamination, which is said to offensive during periods of low water. Three series of analyses ve been carried on at Coshocton by the Ohio State Board of Health. he sampling points chosen were Walhonding Creek and Tuscarawas iver, both above the confluence of Coshocton pollution, and a point n Muskingum River at a proper distance below the confluence of ie two main tributaries where it was reasonably certain that the aters of the two streams and the pollution from Coshocton were horoughly mixed.

TABLE 106.—*Averages of analyses of water from Walhonding Creek and Tuscarawas River above Coshocton and from Muskingum River below Coshocton*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Walhonding Creek above Coshocton	.....	21	e a	0.187	0.045	0.004	0.10	5.4	303	139.0	14.4	
Tuscarawas River above Coshocton	.....	16	....	.128	.028	.003	.05	20.6	303	119.0	29.1	
Muskingum River below Coshocton	113	20	....	.180	.043	.005	.05	19.4	329	120.4	49.2	

a e, earthy.

Comparison of the analyses of water from Walhonding Creek abov Coshocton with those of water from Tuscarawas River shows tha the latter is not so highly colored. The amount of residue is th same as in the Tuscarawas, the alkalinity higher, but the norma hardness less. It is notable that the content of chlorine in th Tuscarawas is higher, the difference being due principally to contam nation from the salt works in the upper part of the basin of tha tributary. The Walhonding has more organic matter than the Tus carawas. In both streams the water is greatly damaged by pollution but the nuisance occasioned thereby is not general, being confine to certain localities near points of discharge of certain city sewers.

WILLS CREEK.

Wills Creek enters the Muskingum from the east a short distanc below Coshocton. It is the drainage outlet of Guernsey County, an the basin comprises also small areas in Noble and Belmont counties The creek is formed by the confluence of Buffalo Fork and Seneca Falls Creek a short distance north of Noble County line, and pursues an extremely winding course to its outlet, running through Guernsey Coshocton, and Muskingum counties and into the Muskingum River The only considerable center of population in the drainage area is Cambridge, a city of 8,241 inhabitants. This is an important coal distributing point, and it contains tin and iron mills, which contribute considerable amounts of wastes to the river. Sewers have been introduced at Cambridge and, although they have not been widely extended, they do their full measure of damage to the stream. Leatherwood Creek, which enters Wills Creek at Cambridge, drains an important mining district and, as a result, is very turbid by reason of a large amount of coal-mine waste.

The Ohio State Board of Health has conducted a series of analyses f water above and below Cambridge on Wills Creek. That above Cambridge is not representative of the character of Leatherwood Creek water.

TABLE 107.—*Averages of analyses of water from Wills Creek above and below Cambridge.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Cambridge	784	23	v a	0.227	0.109	0.017	0.12	26.6	474	136.8	40.7	8
Below Cambridge	464	24	M	.235	.204	.025	.14	10.0	352	92.5	65.6	8

a v, vegetable; M, musty.

The results above set forth indicate a considerable rise in free ammonia, nitrites, and chlorine after the water passes Cambridge. Mr. Benjamin H. Flynn, engineer of the Ohio State Board of Health, is of the opinion that there is not sufficient discharge of sewage from Cambridge to account for so great a rise in the constituents indicating sewage pollution, and that the change is probably due to industrial wastes. The reduction in the amount of turbidity is interesting, as it indicates a possible discharge of coagulating material from the mines, probably sulphate of iron. To this extent, therefore, the industrial pollution may be regarded as a benefit.

LICKING CREEK.

About 20 miles below the confluence of Wills Creek is the city of Zanesville, at which point Licking Creek joins the Muskingum. This stream drains the north of Licking County and part of Knox, Perry, and Muskingum counties. The western part of this basin is level and is devoted to agriculture, while the eastern part is hilly. At the headwaters of the stream are many small towns, the principal ones being Centerburg, Utica, Pataskola, Johnstown, and Granville, having a combined population of 4,270.

Newark, with a population of 18,157, is the commercial center of the basin. It contains many manufacturing industries and several slaughter houses, and these, together with the city sewage, make the river very foul at times.

Analyses of water from Licking Creek above Newark indicate that it is rich in organic matter, yet there is no special evidence of dangerous contamination, while the samples taken from the stream below Newark present the usual contrast.

TABLE 108.—*Averages of analyses of water from Licking Creek above and below Newark.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Newark..	87	13	None.	0.106	0.029	0.002	0.04	1.6	309	184.0	21.3	700	8
Below Newark..	99	14	M[a]	.162	.088	.006	.07	3.0	329	181.4	13.4	5,200	8

[a] M, musty.

The city of Zanesville, with population of 23,538, is the largest center of pollution yet considered in the drainage basin of the Muskingum. The water supply is taken from Muskingum River just above the city, but the water is so impure that steps are now being taken to improve its quality or to procure another source of supply. A sewerage system has been provided, and the manufacturing industries are important. In addition to the contamination from sewers and from these manufacturing plants, the river receives sewerage drainage, which is dangerously polluted by slovenly methods of disposing of garbage and night soil.

The Ohio State Board of Health has conducted three series of examinations, eight samples being taken from each of the following points: Muskingum River above Zanesville, Licking Creek above Zanesville, and Muskingum River below Zanesville. The averages of the results of these examinations are reproduced below.

TABLE 109.—*Average results of analyses of water from Licking Creek above Zanesville and from Muskingum River above and below Zanesville.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Licking Creek above Zanesville	15	0.288	0.059	0.006	0.05	3.2	510	165.3	21.4	2,700	8
Muskingum River above Zanesville	25	.285	.093	.008	.08	10.0	498	114.2	35.9	2,700	8
Muskingum River below Zanesville	24	.324	.098	.009	.08	9.6	530	118.7	23.4	12,000	8

There is a striking similarity in the analyses of the waters from *Muskingum* River and from Licking Creek above Zanesville. In fact,

the determinations practically conform, the only significant departure being in the case of chlorine. In the preceding pages it has been noted that salt works contributed large quantities of waste to the Tuscarawas River, which results in raising the amount of chlorine to a height unwarranted by existing sewage pollution. To this is probably due a part of the excess of chlorine in water in Muskingum River above Zanesville over that in Licking Creek.

In the introduction to this paper it was stated that the chlorine contributed to surface water does not undergo mechanical change similar to that which takes place in the nitrogen compounds, but firmly maintains its identity, fluctuating in amount according to the dilution which it receives from tributaries, or the contributions from sewers and other polluting factors, and when organic matter is completely changed to inorganic compounds, and all other trace of contamination is lost, the chlorine remains an unshaken witness of past pollution. We have also seen in the pages immediately preceding that large amounts of sewage are poured into the streams in the Muskingum Basin. By the time the water reaches Zanesville the organic matter poured in from the cities in the upper part of the basin has been nearly or completely consumed, and that which appears on analysis is undoubtedly of recent origin. But the chlorine in the Muskingum, which is in so great excess over that in Licking Creek, is largely the evidence of pollution both from sewage and from the salt works in the upper part of the basin.

The condition of the water of Licking Creek is so similar to that of Muskingum that it can not be said that either stream is a detriment or a benefit to the other. In the one case we have a water recently polluted, while in the other it appears that the water was at one time more seriously contaminated, but through the effects of oxidation, sedimentation, and dilution the evidences of this contamination have been nearly lost, and the most apparent pollution is that derived from sources not far above Zanesville.

Analyses of the water of the Muskingum below Zanesville show, in a fairly satisfactory manner, the effect of the commingling of the waters of Licking Creek and Muskingum River in conjunction with the wastes of Zanesville.

Below Zanesville, on the Muskingum and on the minor tributaries, there are a number of small towns which, while collectively they contribute some foreign matter, do not influence the character of the water extensively. There is no place of importance until McConnelsville is reached, the county seat of Morgan County, containing 1,825 inhabitants, and provided with water supply and sewers. Just above this place the Ohio State Board of Health has taken a series of samples for examination, the results of which are embraced in the following table.

TABLE 108.—*Averages of analyses of water from Licking Creek above and below Newark.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Newark	87	13	None.	0.106	0.029	0.002	0.04	1.6	309	184.0	21.3	700	8
Below Newark	99	14	M[a]	.162	.088	.006	.07	3.0	329	181.4	13.4	5,200	8

[a] M, musty.

The city of Zanesville, with population of 23,538, is the largest center of pollution yet considered in the drainage basin of the Muskingum. The water supply is taken from Muskingum River just above the city, but the water is so impure that steps are now being taken to improve its quality or to procure another source of supply. A sewerage system has been provided, and the manufacturing industries are important. In addition to the contamination from sewers and from these manufacturing plants, the river receives sewerage drainage, which is dangerously polluted by slovenly methods of disposing of garbage and night soil.

The Ohio State Board of Health has conducted three series of examinations, eight samples being taken from each of the following points: Muskingum River above Zanesville, Licking Creek above Zanesville, and Muskingum River below Zanesville. The averages of the results of these examinations are reproduced below.

TABLE 109.—*Average results of analyses of water from Licking Creek above Zanesville and from Muskingum River above and below Zanesville.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Licking Creek above Zanesville	15	0.288	0.059	0.006	0.05	3.2	510	165.3	21.4	2,700	8
Muskingum River above Zanesville	25	.285	.093	.006	.08	10.0	498	114.2	35.9	2,700	8
Muskingum River below Zanesville	24	.324	.088	.009	.08	9.6	530	118.7	23.4	12,000	8

There is a striking similarity in the analyses of the waters from *Muskingum* River and from Licking Creek above Zanesville. In fact,

determinations practically conform, the only significant departure ng in the case of chlorine. In the preceding pages it has been noted t salt works contributed large quantities of waste to the Tuscara- s River, which results in raising the amount of chlorine to a height warranted by existing sewage pollution. To this is probably due art of the excess of chlorine in water in Muskingum River above nesville over that in Licking Creek.

n the introduction to this paper it was stated that the chlorine con- buted to surface water does not undergo mechanical change similar that which takes place in the nitrogen compounds, but firmly main- ns its identity, fluctuating in amount according to the dilution ich it receives from tributaries, or the contributions from sewers l other polluting factors, and when organic matter is completely nged to inorganic compounds, and all other trace of contamination lost, the chlorine remains an unshaken witness of past pollution. e have also seen in the pages immediately preceding that large ounts of sewage are poured into the streams in the Muskingum sin. By the time the water reaches Zanesville the organic matter ured in from the cities in the upper part of the basin has been arly or completely consumed, and that which appears on analysis undoubtedly of recent origin. But the chlorine in the Muskingum, hich is in so great excess over that in Licking Creek, is largely the vidence of pollution both from sewage and from the salt works in he upper part of the basin.

The condition of the water of Licking Creek is so similar to that of Muskingum that it can not be said that either stream is a detriment r a benefit to the other. In the one case we have a water recently pol- luted, while in the other it appears that the water was at one time more seriously contaminated, but through the effects of oxidation, sedimentation, and dilution the evidences of this contamination have been nearly lost, and the most apparent pollution is that derived from sources not far above Zanesville.

Analyses of the water of the Muskingum below Zanesville show, in a fairly satisfactory manner, the effect of the commingling of the waters of Licking Creek and Muskingum River in conjunction with the wastes of Zanesville.

Below Zanesville, on the Muskingum and on the minor tributaries, there are a number of small towns which, while collectively they con- tribute some foreign matter, do not influence the character of the water extensively. There is no place of importance until McConnels- ville is reached, the county seat of Morgan County, containing 1,825 inhabitants, and provided with water supply and sewers. Just above this place the Ohio State Board of Health has taken a series of samples for examination, the results of which are embraced in the following table.

TABLE 110.—*Analyses of water from Muskingum River above McConnelsville*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1899.												
April 28	35	10	None.	0.178	0.038	0.004	0.08	5.8	269	101.1	56.8	
May 24	271	28	e[a]	.234	.060	.007	.08	3.8	304	73.0	50.0	1
June 22	(b)	20	e	1.064	.152	.003	.13	2.1	1,784	44.5	7.6	7
July 25	206	.....	v	.230	.058	.009	.26	11.8	296	90.8	21.8	1
August 30	114	22	v	.228	.156	.018	.04	14.8	329	147.2	40.0	1
September 27	65	20	e	.164	.046	.012	.10	14.3	306	152.2	None.	
October 17	52	10	v, e	.140	.028	.015	.06	15.7	308	152.2	31.8	
November 22	52	20	None.	.162	.034	.004	.11	19.0	315	142.2	49.0	
Average	.....	19	.....	.300	.075	.009	.11	10.9	489	112.9	32.1	1

[a] e, earthy; v, vegetable. [b] Enormous.

From McConnelsville to Marietta, at the mouth of the river, the are the usual number of small villages, the effects of which upon t character of the water are not important. Marietta, with populati of 13,384, has considerable manufacturing and a public water supp and sewerage system, which empties into Ohio River, so that it has effect on the Muskingum. There is, however, considerable manufa turing sewage poured into the latter.

TABLE 111.—*Analyses of water from Muskingum River above Marietta.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1899.												
April 28	52	10	p[a]	0.102	0.056	0.002	0.10	5.7	275	112.4	57.9	
May 24	600	25	e	.216	.046	.009	.09	2.9	396	71.8	22.4	
June 22	(b)	22	e	.464	.136	.004	.12	9.3	1,017	93.9	52.0	3
July 25	210	28	v	.296	.066	.008	.05	8.2	234	93.6	17.0	
August 30	80	20	e	.202	.052	.012	.04	8.9	245	122.2	55.0	
September 27	80	25	e	.158	.022	.010	.05	13.5	304	143.6	6.4	
October 17	110	10	m	.120	.016	.008	.03	11.2	300	146.8	62.0	
November 22	49	10	None.	.112	.016	.004	.16	17.9	322	144.2	39.4	1
Average	.....	19	.....	.300	.050	.007	.08	9.7	390	116.1	39.0	1

[a] p, peaty; e, earthy; v, vegetable; m, moldy. [b] Enormous.

The above analyses show fairly well the character of the water co *tributed to* the Ohio system from the Muskingum Basin. The wat

improves in quality between Zanesville and the mouth of the river, and therefore the effect of the Muskingum system on the Ohio is less damaging than might be supposed after considering the points of pollution in the Muskingum.

The analyses given certainly show that the Muskingum is in many places a very foul stream. Indeed, there are few points at which water can be collected in its normal and undamaged state. This stream is certainly not a proper one to use as a sewage course, for its greatest value is in its water resources. It is not good for much as a source of power, its navigation is insignificant, and the humid climate of the country makes its use for irrigation unnecessary. There are, perhaps, certain points along the course of the stream which are fit places for the harvesting of an ice crop, but the Muskingum can never be an extensive ice field. Therefore the water-supply value of the river is practically the only important one, and, as has been shown, this is greatly damaged. It is unwise to utilize for domestic purposes the waters of the Muskingum and its tributaries at almost any point unless efficient means of purification are adopted. On the other hand, the character of the river basin is such that self-purification readily takes place. There is no doubt that if means were used to purify the sewage which is now poured into the stream, the waters could, in certain places, be used as a water supply without any treatment.

SCIOTO RIVER.

DRAINAGE BASIN.

The drainage basin of Scioto River occupies a long, narrow strip of country in the central and southern part of Ohio, extending from the Lake Erie drainage divide on the north to the Ohio River at Portsmouth on the south, and comprising about 6,400 square miles. The source of the river is in Auglaize County, in a portion of the drainage area which juts westward and lies north of the Great Miami Basin. Thence it runs in a generally southerly direction 40 miles, to a point a little southwest of the city of Marion. The fall along this section is nearly 500 feet. Thence its course is almost due south. It passes through the city of Columbus, capital of the State of Ohio, the fall from Marion to this point being 430 feet. Continuing south, the river joins the Ohio at Portsmouth, 110 miles above Cincinnati. The fall of the river between Columbus and Portsmouth averages 26 feet per mile along the entire length of 130 miles. The entire course of the river, measured in a straight line, is 175 miles, although when actually traversed it amounts to nearly 210 miles.

The tributaries are not so large nor so important in this drainage area as they are in the Muskingum, by reason of the fact that the watershed is somewhat narrow. The most important tributaries and the area drained by *them* are named below.

TABLE 112.—*Drainage area of Scioto River and tributaries.*

	Sq. miles
Olentangy River at mouth at Columbus	54[illegible]
Big Walnut Creek at mouth	51[illegible]
Darby Creek at mouth	5[illegible]
North Fork of Paint Creek	2[illegible]
Main Fork of Paint Creek above junction with North Fork	82[illegible]
Paint Creek at mouth	1,08[illegible]
Scioto River at southern boundary of Marion County	62[illegible]
Scioto River at Columbus, above junction with Olentangy River	1,13[illegible]
Scioto River at Columbus, below junction with Olentangy River	1,68[illegible]
Scioto River at Circleville and Darby creeks	3,27[illegible]
Scioto River at Chillicothe	3,92[illegible]
Scioto River at mouth	6,40[illegible]

The principal economic value of Scioto River lies in its availability as a source of water supply. It is not an important power stream, although in past years the aggregate of power developed by the numerous plants along it was fairly large, but on account of the flatness of the area there is not sufficient opportunity to develop many or extensive power sites, those which have been utilized being of the capacity which are found necessary to the development of saw and grist mills only. The development of cheaper power in other parts of the country and the improvement of transportation facilities have led to the abandonment of a large number of the power privileges afforded by the Scioto, and very few of those that remain are of much value. Even as a source of water supply the opportunities for conservation are not all that could be desired, for it is necessary in some places to pump the water directly from the flowing stream into distributing reservoirs, the storage capacity of which is not in every case sufficient to allow the water to be properly stored and purified. This condition aggravates the dangers due to polluted river water, for under these circumstances pollution becomes more certain in its unfavorable effects upon the water consumer than it could be if a longer term of storage were afforded.

NORMAL WATER IN THE SCIOTO BASIN.

There are no public records of analyses of a distinctively normal water in the Scioto Basin. The work of the Ohio State Board of Health has so far been confined almost entirely to the examination of polluted streams, and it is only from the series of analyses made near the headwaters of the rivers and above the highest points of appreciable sewage pollution that we are able to obtain any ideas concerning the character of these waters in their normal state. In the basin of the Scioto it is probable that the analysis affording the best idea of the character of its normal water is that which has been made of samples collected above the city of Kenton, in Harding County. The *population* above the city is almost entirely rural, there being a few *small villages*, containing from 25 to 100 inhabitants, and while the

contamination which they impart to the headwaters of the Scioto is hardly appreciable, yet it can not be said that the water which reaches Kenton is normal. It is probably nearly so, and for all practical purposes can be so considered. The analyses of this water appear in the following table:

TABLE 113.—*Analyses of water from the Scioto River above Kenton.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 12	4	None.	0.514	0.062	0.024	1.50	2.0	730	210	226	1,300
July 16	4	e[a]	.462	.098	.003	.42	1.0	805	232	.....	480
August 25	2	None.	.292	.084	.000	.00	2.5	625	234	130	430
September 25	4	e	.238	.028	.000	.00	3.8	670	226	122	270
October 23	3	M	.240	.030	.000	.00	3.3	605	252	112	390
December 1	5	M	.638	.571	.030	9.38	1.5	1,075	104	510	1,900
Average	4	.....	.379	.145	.010	1.900	2.3	752	210	183	790

[a] e, earthy; M, musty.

POLLUTION IN BASIN OF THE SCIOTO.

Kenton is a city of 6,852 inhabitants, provided with sanitary sewers and storm-water drains. Both systems discharge into the river. The effect upon the water is easily appreciable upon examination of the following table:

TABLE 114.—*Analyses of water from the Scioto River below Kenton.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.										
June 12	4.5	0.430	0.142	0.026	1.60	4.0	710	214	228	.....
July 16	3.0	1.720	.476	.000	.00	4.5	720	32	...	5,800
August 25	2.0	1.328	.384	.010	.00	6.5	605	232	118	2,400
September 25	3.5	.360	.764	.003	.00	12.5	645	238	114	4,200
October 23	3.0	.588	2.160	.005	.00	18.0	650	258	114	17,000
December 1	5.0	.624	.584	.030	.44	2.0	975	118	466	14,000
Average	*3.5*	*.841*	*.751*	*.012*	.....	7.9	718	182	173	8,700

Continuing down the Scioto no further important source of pollution is met with until the mouth of Little Scioto River is reached. In the drainage area of this river is the city of Marion, containing according to the Twelfth Census, 11,862 inhabitants. Sewer outlets enter the river a short distance above its confluence with the Scioto and there are published records of analyses of the water from Little Scioto, above and below the sewer outfall, which are reproduced in Table 115.

TABLE 115.—*Analyses of water from Little Scioto River above and below the Marion sewers' outfall.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Marion	3	0.489	0.378	0.013	1.25	5.3	469	204	75	8,200	6
Below Marion	3	.464	1.897	.037	1.31	16.5	553	231	85	9,500	6

The report of the analyses of water from Little Scioto River, taken below the Marion sewer outlets, shows clearly the foulness of the contribution which the system receives from this tributary.

The next point of examination of the Scioto below the confluence of Little Scioto is the Ohio Girls' Industrial Home, which contains a population of over 400. A complete system of sewers is here provided, the wastes from which are poured directly into the river. Table 116 shows clearly the effects of this contamination upon the stream.

TABLE 116.—*Analyses of water from Scioto River above and below the Ohio Girls' Industrial Home.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above industrial home.	3.0	0.334	0.086	0.008	0.176	6.6	509	175	123	1,600	
Below industrial home.	3.0	.320	.103	.009	.206	7.5	507	173	126	1,600	

next important center of pollution is the city of Columbus, enters Olentangy River, the largest stream tributary to the

Above the confluence of these two rivers the State Board of has made three series of examinations, one at Wyandot Grove, Columbus pollution, another about 3 miles below at Jones's where the city's sewage begins to have effect; and a third at ky street bridge, near the mouth of the Olentangy. The of this interesting series of examinations appear below.

LE 117.—*Analyses of water from the Scioto River at Wyandot Grove.*

[Parts per million.]

ollec-	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
8.											
.....	2.0	s[a]	0.260	0.040	0.002	0.200	4.0	445	194	52	730
.....	3.0	.....	.378	.028	.002	.170	5.5	500	182	94	910
23....	2.0	None.	.344	.096	.003	.030	3.8	440	172	88	290
er 23-	1.5	e	.316	.098	.002	.030	7.8	550	176	126	300
21 ...	2.0	e	.268	.048	.002	.050	7.7	585	200	140	300
er 3 ..	5.0	e	.366	.100	.020	6.300	1.5	467	146	132	2,000
rage.	2.5	.....	.322	.068	.005	1.150	5.0	498	178	105	740

[a] s, sweetish; e, earthy.

TABLE 118.—*Analyses of water from Scioto River at Jones's dam.*

[Parts per million.]

ollec-	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
).											
....	2	None.	0.276	0.037	0.002	0.340	4.5	455	194	48	810
....	3	None.	.398	.028	.003	.200	3.8	510	184	104	400
....	2	m[a]	.380	.092	.003	.080	4.1	450	178	80	590
....	2	e	.306	.088	.003	.000	7.3	510	176	116	350
....	2	e	.296	.082	.006	.050	7.4	454	192	124	700
....	5	e	.354	.102	.025	6.500	1.7	464	140	136	2,200
age.	3	.....	.335	.071	.007	1.20	4.8	489	177	101	840

[a] m, moldy; e, earthy.

TABLE 119.—*Analyses of water from Scioto River at Sandusky street bridge.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 13	2.0	None.	0.342	0.110	0.007	0.320	7.0	480	190	62	1,470
July 17	3.0	M[a]	.376	.048	.002	.260	4.0	480	184	92	1,030
Aug. 23	2.0	M	.394	.200	.015	.070	10.1	445	180	78	4,540
Sept. 23	2.0	M	.420	.280	.005	.000	11.5	460	152	106	10,800
Oct. 21	1.5	d	.392	.086	.004	.040	8.7	525	158	98	1,150
Dec. 3	6.0	d	.418	.110	.025	5.820	2.3	474	144	136	10,200
Average	2.5	.....	.390	.139	.010	1.090	7.2	477	168	95	4,900

[a] M, musty; d, disagreeable.

OLENTANGY RIVER.

The Olentangy drains an extremely narrow basin lying east of and running parallel throughout the greater part of its length to the middle section of the main river. It rises in the northern part of Morrow County and flows for a short distance northwestward into Crawford County, passing the city of Galion, whence it takes a southerly course, running within 5 miles of the city of Marion, and after flowing through Delaware County and past the city of Delaware enters the Scioto at Columbus.

The highest point of pollution on Olentangy River is Galion, a city of 7,282 inhabitants. The population above this city is sparse, and the water in the river is therefore nearly normal. The State Board of Health conducted in the year 1898 a series of analyses of the water in the river above and below the outlet of Galion sewers, the average results of which appear below in Table 120. As the analyses indicate, the effect of Galion sewage on the river is marked.

TABLE 120.—*Analyses of water from Olentangy River above and below Galion.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Galion	3.5	M[a]	0.476	0.132	0.007	0.640	8.3	463	206	69	450	
Below Galion	3.5	M	.994	4.606	.111	.640	50.7	873	262	190	49,000	

[a] M, musty.

point of pollution worthy of consideration next below Galion is are, the largest city in and the county seat of Delaware County. tributaries enter the river between these two cities, so that the is many times larger at Delaware than it is 40 miles above, at . The water in the river above Delaware is markedly improved, it be expected, but after receiving the contents of the city sewers nditions are again undesirable, as shown in the following table:

21.—*Analyses of water from Olentangy River above and below Delaware.*

[Parts per million.]

of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
elaware	3.5	M[a]	0.322	0.073	0.004	0.890	2.5	408	186	61	1,030	6
elaware	3.5	M	.357	.118	.017	.810	14.5	484	188	96	1,130	6

[a] M, musty.

re are of public record two series of analyses in the lower part ntangy River. The sampling point at Olentangy Park is above ious pollution of Columbus, while the other is at Dublin Bridge, city of Columbus, just above the confluence of the Olentangy ioto rivers.

LE 122.—*Analyses of water from Olentangy River at Olentangy Park.*

[Parts per million.]

collec-	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
3.											
	3.0	e[a]	0.426	0.062	0.003	0.240	3.0	390	178	50	680
	2.5	None.	.334	.094	.003	.050	5.8	450	206	74	700
3	3.0	e	.354	.076	.002	.000	10.2	555	204	134	400
	2.0	e	.286	.072	.005	.120	7.7	620	226	122	280
	5.0	e	.362	.066	.020	4.950	3.0	404	126	98	1,800
rage	3.0		.353	.074	.007	1.070	5.9	484	188	96	770

[a] e, earthy.

TABLE 123.—*Analyses of water of Olentangy River at Dublin bridge, Colu*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 13	2.0	e[a]	0.294	0.066	0.011	0.210	5.5	415	202	48	1
July 17	3.0	....	.388	.058	.004	.320	3.2	360	166	44	1
Aug. 23	2.0	M	.302	.096	.002	.020	5.4	440	194	72	1
Sept. 23	2.0	M	.352	.126	.001	.000	8.5	525	192	110	
Oct. 21	1.5	M	.294	.036	.002	.000	8.7	585	218	112	
Dec. 3	10.0	M	.372	.074	.020	4.800	3.0	387	132	96	4
Average.	3.4	....	.334	.076	.007	.890	5.7	452	184	80	1

[a] e, earthy; M, musty.

The analyses in Table 123 show the character of the water cont uted to the Scioto system by its main tributary. Comparison of various tables of analyses of the water of the Olentangy will s that at the mouth of the river the condition of the water is far be than it is below Galion, near its headwaters. Along the lower le of the river, however, the water is highly polluted and is unfit for as a public supply without purification. The other values of river are not seriously impaired, but as its resources are confi almost entirely to those of water supply, there is little that rem as available assets.

Below the confluence of the Scioto and the Olentangy the bed the main river is very flat, so that it becomes in places almo slack-water stream. The storage advantages are thus increased, the river has remarkable self-purifying powers. Below Colum the first sampling point is Frank road bridge, which is situated v down toward the lower part of the city. Analyses of the water ta at this point show the effect of the mixture of the upper Scioto a Olentangy waters and the sewage from Columbus.

TABLE 124.—*Analyses of water from the Scioto River at Frank road bridge, Columbus.*

[Parts per million.]

...e of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.											
...ne 11	2.0	d[a]	1.130	2.322	.....	0.030	16.0	495	238	86	8,900
...ly 17	4.0	d	.896	1.644	0.188	.000	13.0	440	182	84	64,000
...gust 23	4.0	d	1.136	3.824	.000	.000	21.0	520	256	94	195,000
...ptember 23	3.0	d	.876	7.600	.....	.000	39.0	680	330	112	250,000
October 21	5.0	d	2.340	10.170	.000	.000	41.5	765	346	92	183,000
December 4	4.0	o	.780	.880	.070	4.420	6.0	472	160	134	135,000
Average	4.0	....	1.193	4.406	.043	.74	22.7	562	252	100	140,000

[a] d, disagreeable; o, oily.

Seven miles below Frank road bridge is Shadeville bridge, at which a series of analyses was made, the average results of which are reproduced in the table below:

TABLE 125.—*Analyses of water from the Scioto River at Shadeville bridge.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses contributing to average.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Shadeville bridge	3.5	0.806	3.352	0.121	0.121	19.3	510	285	74	7,200	5

Circleville is a village of 6,991 inhabitants, situated near the central part of Pickaway County, about 30 miles below Columbus. A series of examinations made of the river water taken at Main street bridge has been made by the State Board of Health, the reports of which are set forth in Table 126.

TABLE 126.—*Analyses of water from the Scioto River at Circleville.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.											
July 22	10.0	e[a]	0.660	0.118	0.030	1.13	1.7	285	114	54	14,0
Aug. 26	2.0	.....	.378	.352	.023	.16	5.5	395	228	20	6
Sept. 27	1.5	e	.320	.210	.007	.....	11.7	400	242	28	5
Oct. 25	2.5	M	.314	.534	.045	.13	11.2	435	282	28	8
Dec. 4	5.0	M	.424	.344	.050	2.68	2.5	393	144	76	3,5
Average	4.0	.....	.419	.312	.031	.82	6.5	382	202	41	3,9

[a] e, earthy; M, musty.

It will be seen that the water at Circleville has been purified to a considerable extent in its course from Columbus down. Free ammonia, nitrites, and chlorine, the standard indicators of sewage pollution in water, are very much reduced, and the analyses at the lower point indicate better conditions.

The only important point of pollution below Circleville is the city of Chillicothe, containing 12,975 inhabitants. No analyses of water taken below this place are recorded. Sixty miles below Chillicothe the river enters the Ohio at Portsmouth.

Little remains to be said concerning the Scioto. The conditions of the river are wholly favorable to the purification of foreign matters that are poured into it, but the raw sewage it receives from the various cities constitutes a source of contamination that can not be overcome. The river is little more than a dumping ground for refuse, and its misuse affords a good example of the wanton destruction of a valuable resource; but the work of the State Board of Health of Ohio bids fair to be fruitful, so that we may confidently expect great improvements in sanitation in the Scioto Valley.

OHIO RIVER AT CINCINNATI.

On Ohio River, below the mouth of the Scioto, a series of notable investigations has been made by Mr. George W. Fuller, following his work on the water supplies of Louisville and Cincinnati, and the reports of these inquiries are probably the ablest that have been presented on the subject in this country. The Cincinnati report, in a concise, definite, and methodical manner, gives just the facts necessary to the discussion, and shows the character of the water of the Ohio as it comes down to Cincinnati, bearing traces of all the pollution heretofore considered, as well as a large amount derived from tributaries that have not yet been investigated, or the investigations of which are not of public record. Therefore one can arrive at an

ınding of the character of the Ohio River at this point no ıan by consulting the above-mentioned report, parts of which convenience, here reproduced.[a]

outset it is imperative, for a clear understanding of this report, that ıld be fixed in mind the two most characteristic features of the local ɛr, as follows:

wide range in the amount of suspended matter present in the water.

great variations in the nature of the suspended matter, and especially in ! the particles.

rehensive idea of the amounts of suspended matter found at different his water during the year 1898 is shown in the following summary:

TABLE 127.—*Turbidity of Ohio River water.*

[Parts per million.]

er of days, 1898.	Corresponding range of suspended matter.	Number of days, 1898.	Corresponding range of suspended matter.
	(a)	29	501–1,000
	11– 50	5	1,001–2,000
	51–100	1	(b)
	101–250	Average	230
	251–500		

[a] Less than 10. [b] Over 2,000.

at variation in the character and size of the suspended matters is best d by the following table, in which there is indicated the different : subsiding values (or sizes) of two extreme types of the river water. characteristic of the water during the early portion of a heavy freshet, s heavily laden with silt and fairly coarse clay, and Type II is represent- the water during later portions of rises, while it is charged to a greater legree with very fine, minute particles of clay.

128.—*Periods of subsidence necessary with water from Ohio River at Louisville, Ky.*

riod of subsidence (hours).	Suspended matter in parts per million.		Per cent removed.	
	Type I.	Type II.	Type I.	Type II.
	2,333	205	0	0
	932	81	60	55
	653	80	72	56
	396	79	83	56
	350	73	85	58
	300	61	87	63
	259	44	89	67
	210	36	91	70
	186	31	92	72

ɔn Types I and II there are found in the course of a year an almost end- ber of intermediate combinations.

* * * * * *

rect causes of these variations in the Ohio River water are the rises or *which are so characteristic* of this stream. Indirectly there are a number

t on investigations into the purification of the Ohio River water, 1899, p. 9 et seq.

of factors which exert much influence. Among them are the amount, rate, dis bution, and frequency of the rainfall in the valley, and also the surface geol topography, area, and length of the watershed, and the condition of the soil at time of heavy rains. To solve the problem of establishing the relation betw the composition of this river water and the factors affecting it is a complex mat and so far as our knowledge goes there are available no adequate data for the p pose, nor are such data being obtained.

* * * * * * *

The watershed of the Ohio River above the intake of the new Cincinnati wa works at California has an area of about 70,600 square miles. This area inclu portions of the States of Ohio, New York, Pennsylvania, Virginia, North Ca lina, West Virginia, and Kentucky.

Above the intake of the Front street pumping station (used during these te the area of the watershed is estimated at 72,400 square miles. In addition to area at the new intake the last area includes that of the watershed of the Li Miami River, and that of the Ohio River itself between the Little Miami and Front street intake, a distance of about 6 miles.

About half a mile downstream from the Front street intake the Licking Ri empties into the Ohio River on the Kentucky side. At this point the nor width of the river is about 1,000 feet. The Front street intake is situated ab 200 feet from the Ohio shore, and in a straight line is distant about 4,000 feet fr the mouth of the Licking. Under some conditions of river stages and of wi storms the waters of the Licking reach the Front street intake.

The Licking River has a watershed of about 3,300 square miles. Adding t to the above, there is obtained 75,700 square miles as a total area of the wa shed of the Ohio River above the present intake opposite the city.

TABLE 129.—*Table showing the monthly rainfall in inches at various station the Ohio River Valley for the year 1898.*

Station.	Jan	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	T
Cincinnati, Ohio..	7.76	2.21	6.70	1.15	3.03	1.58	3.26	2.61	2.62	2.90	2.69	2.46	
Portsmouth, Ohio	10.03	1.69	5.14	2.05	3.53	3.13	5.27	6.92	1.97	3.59	2.54	2.76	
Catlettsburg, Ky.	8.05	2.48	6.93	2.19	4.83	4.52	4.84	6.93	2.10	4.14	2.65	2.83	
Point Pleasant, W. Va.....	8.04	1.93	5.81	1.48	3.51	2.87	2.79	6.40	2.07	3.15	2.67	2.57	
Parkersburg, W. Va.....	5.73	2.24	5.43	2.17	2.76	4.98	4.38	4.66	2.09	3.90	2.50	2.16	
Marietta, Ohio....	5.74	2.39	6.03	2.30	2.77	5.04	5.20	5.31	3.69	4.24	3.15	2.21	
Wheeling, W. Va.	4.79	2.50	5.15	3.72	3.63	2.98	5.81	7.82	3.24	3.37	2.66	3.03	
Pittsburg, Pa.....	3.40	1.60	5.45	1.60	3.99	3.98	2.56	4.01	1.06	3.85	2.34	1.90	
Oil City, Pa.....	5.32	2.53	5.74	2.13	4.64	4.56	4.45	6.73	2.11	5.18	4.33	2.90	

TABLE 130.—*Table showing the normal monthly rainfall in inches at vari stations in the Ohio River Valley.*

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	T
Cincinnati, Ohio..	3.5	3.7	3.3	3.2	3.4	4.4	3.4	3.7	2.4	2.4	3.3	3.2	
Portsmouth, Ohio	3.5	3.2	3.5	3.2	3.5	4.0	3.9	3.4	2.8	2.8	2.9	3.5	
Catlettsburg, Ky.	4.3	4.0	4.2	3.2	4.0	3.8	4.4	3.6	2.9	2.7	3.5	2.9	
Point Pleasant, W. Va.....	3.5	4.1	3.9	3.7	3.5	4.2	4.4	4.0	2.4	2.4	3.1	2.7	
Marietta, Ohio....	3.1	3.1	3.2	3.3	3.9	4.1	4.4	3.9	3.1	3.1	3.1	3.4	
Parkersburg, W. Va	3.9	3.8	3.0	3.2	3.5	4.0	4.4	3.8	3.1	2.3	2.8	2.3	
Wheeling, W. Va.	3.4	3.1	2.6	2.8	4.1	3.7	3.7	4.1	2.8	2.6	2.7	3.0	
Pittsburg, Pa.....	2.6	2.5	2.8	3.0	3.5	3.6	4.0	3.4	2.9	2.8	2.6	2.9	
Oil City, Pa.....	3.3	3.6	2.8	2.7	3.9	4.6	3.6	2.7	3.4	2.6	3.2	2.8	

ON OF THE FREQUENCY, INTENSITY, AND DURATION OF RISES OR FLOODS THE OHIO RIVER AT CINCINNATI DURING 1898 WITH THE NORMAL.

bject is one of great importance from a practical standpoint, because it a factors which directly produce the large quantities of and variations in ers suspended in the river water. In view of the fact that these sus- atters are a point of vital significance in connection with the construc- n applicable system of clarification and purification, and also in the and economy of its operation, it is necessary to know, at least in general ow nearly normal was the suspended matter during these tests, and t would be very desirable to be able to foretell the conditions with regard pended matters due to rises, as an aid in the operation of a plant.

mplish these purposes involves a study of the frequency, intensity, and of the rises in the river. It is an easy matter to deal with the first of tors, except when the rises overlap each other; but to establish a relation suspended matter, both in amount and character and the intensity and of rises, is a very difficult and perplexing problem. At the beginning of the rapidity with which the water rises seems to be a great factor, and rapid is the rise the greater is the amount of suspended matter and also ntage of silt. When the rise is of a long duration it is found that, with rs coming from the head of the valley, the weight of suspended matters y decreases, but the percentage of clay steadily increases, owing to the n of silt in the stream itself.

ow it is best to arrange the available data to throw light upon these not wholly clear to us, since all efforts in this direction are wholly arbi- d of necessity incomplete. However, it is believed that a comparison of sity and number of rises in the river with the rises for the past ten years as good a comparison for this purpose as can be obtained. In the follow- , therefore, are given the number of days on which the river was rising ely, rapidly, very rapidly, and when there was developing an extreme

31.—*Number of days in the year on which the Ohio River was rising at various rates during the last ten years.*

Year.	Rate of rise in feet per day.			
	1.0-2.9.	3.0-5.9.	6.0-11.9.	Over 12.
	66	12	3	0
	63	31	4	0
	44	24	4	0
	33	10	5	1
	34	23	2	0
	24	8	4	0
	26	11	5	1
	47	24	2	0
	45	21	2	1
	54	25	7	0
verage	44.6	18.9	3.6	0.3

TABLE 132.—*Summary of amounts of the several constituents found in water Ohio River during the year 1898.*

Constituent.	Parts per million.		
	Maximum.	Minimum.	Normal
Total suspended matter	2,333.0	24.0	230.
Suspended organic matter (nitrogen as albuminoid ammonia)	0.758	0.022	0.
Total dissolved residue	223.0	67.0	120.
Total nitrogenous organic matter	0.868	0.106	0.
Nitrogen as free ammonia	0.074	0.008	0.
Nitrogen as nitrites	0.030	0.000	0.
Nitrogen as nitrates	1.34	0.37	0.
Chlorine	44.0	3.0	10.
Sulphuric acid	46.0	13.0	24.
Normal hardness	57.0	11.0	33.
Alkalinity	70.0	20.0	45.
Microscopic organisms per cubic centimeter	40.0		
Carbonic acid	47.0	6.0	26.
Bacteria per cubic centimeter	150,000	1,000	20,0

Odor.—The river water ordinarily has a slight odor characteristic of surfac waters, the nature and intensity of which are somewhat variable. At differen times the odor is musty, aromatic, resinous, and vegetable. The latter is mo noticeable after heavy rains during the warm portions of the year. These odo become more pronounced upon heating the water, but, so far as noted durin these tests, there is a practically complete absence of disagreeable or objectio able odors.

Color.—Independent of the suspended matter in it the normal river water practically colorless, although in absolute terms it contains a small but measu able amount of color. It seems quite probable that, at times following certai kinds of rises in the river, there is an appreciably larger amount of dissolve color in the water than is normally the case; but experience shows that ordin rily it is easier to remove the unusual amounts of dissolved color than is the ca with the finest particles of suspended clay. After passage through a Paste filter or a fine paper filter the water contains no color which is ordinarily visibl

Taste.—Ordinarily the river water has an earthy taste, which, however, do not become disagreeable except at times of great turbidity. Freed of its su pended matter, this water has a very satisfactory and agreeable taste.

Appearance.—The turbidity of the river water is such that its appearance almost always unsatisfactory and uninviting, and for about half of the time it so turbid that it is repulsive when considered for domestic use.

Weight of suspended matters.—When expressed in parts by weight per millio parts of water by volume, the suspended matters in this water normally rang from 20 to 2,500 and average about 230 parts.

Character of suspended matters.—In character as well as in amount of suspended matter the river water possesses a wide and rapidly changing degree of variability. The water in the course of the year contains an almost endless combination of varying proportions of fine sand made up of particles of quartz and hard silicates, with high specific gravity and a diameter larger than 0.002 inch; of silt with its intermediate size, specific gravity, and composition; and of very fine clay particles of aluminum silicate, with varying degrees of hydration, of low specific gravity, and of a size ranging from 0.0002 inch to less than 0.00001 inch.

Amount of organic matter.—The organic matter in the river water ranges from an amount which is fairly normal for Eastern waters to quantities (during rises) which are excessive, as judged by the data for many years collected from rivers not located in this general section of the country. The local data summarized above are a striking proof of the fact that it is not the amount but the character of the organic matter which is of importance from a sanitary standpoint.

Character and stability of organic matter.—From the immediately adjoining portion of the watershed there is quite an amount of sewage pollution. Owing to the large dilution, the deleterious effect of this is greatly attenuated. By no means is it eliminated at times of comparatively clear water, but during rises this crude organic matter to a considerable degree seems to be united and attached to particles of suspended matter, and thus carried to the bottom.

The consequence of this dilution and sedimentation is that the water contains very little organic matter, except that of a fairly stable character coming from the washings of the surface of the earth. With water taken from the new intake, above the local sources of pollution, this will be true to a still greater degree.

Alkalinity.—The alkalinity is caused by the carbonates and bicarbonates of lime and magnesia, and in a measure corresponds to temporary hardness (bicarbonates). It is the alkalinity which measures the capacity of the water to decompose sulphate of alumina and other coagulating salts. This water contains an average and minimum alkalinity of 45 and 20 parts per million, respectively. By these amounts of alkalinity there can be decomposed, respectively, about 6.5 and 3 grains per gallon of sulphate of alumina of ordinary composition, assisted by the average absorption of chemical by the suspended matters in the water.

Incrusting constituents.—Those constituents of water which produce incrustations in steam boilers comprise the sulphates, chlorides, and perhaps nitrates of lime and magnesia. In this water they are present (on an average of 33 parts per million) to a degree greater than in most of the Eastern waters, but smaller than in the waters farther west. On the whole, this water is a good one for boiler purposes, so far as incrusting constituents are concerned.

Gaseous constituents.—Atmospheric oxygen is apparently present in this water during cold weather to about the limit of saturation, and during the warm season there is contained in the water rather more oxygen than is the case with some surface waters, although the quantity at times becomes only about 40 per cent of that found during the winter. Carbonic acid (carbon dioxide) is present in this water to a degree which is apparently high, according to the limited data available from Eastern sources, but much lower than is the case with waters farther west coming from limestone regions.

Taking together atmospheric oxygen and the carbonic acid, they make the natural conditions quite favorable for the corrosion of unprotected iron receptacles, but the corrosion of lead pipes is promptly arrested by the action of dissolved constituents of the water itself.

Numbers and kinds of bacteria.—On an average the numbers of bacteria in the

river water (about 20,000 per cubic centimeter) are rather higher than in the nary river water. The range is also very great, 1,000 to 150,000, and is assoc very intimately with the rises of the river.

At the present point of intake, opposite the city, a considerable number o bacteria are of sewage origin. These sewage bacteria will be largely al apparently in the water taken from the new intake at California.

Microscopic organisms.—The turbidity of the Ohio River water was so during the larger part of the year 1898 that the sunlight was excluded to a d practically inhibiting the growth of algæ and similar micro-organisms. W the river water was low and fairly clear these organisms were present in cons able numbers, but did not become of practical significance. The dissolved stituents (such as nitrates) in the river water, and especially at times of low w are well adapted, however, as a food for the organisms which also require light for their development.

TABLE 133.—*Suspended matter in water of Ohio River at Cincinnati from Jan 10 to March 23, 1898, with corresponding stages of height of river in feet*

[In parts per million.]

Date.	Stage of river.	Suspended matter.	Date.	Stage of river.	Suspended matter.	Date.	Stage of river.	S per ma
Jan. 10	33.0	2,333	Feb. 3	25.0	372	Feb. 24	33.0	
11	32.2	1,151	4	21.5	184	25	33.2	
12	35.4	1,024	5	18.7	134	26	32.4	
13	38.0	719	6	16.5	113	27	30.7	
14	37.7	578	7	14.7	108	28	28.0	
15	39.7	470	8	14.0	96	Mar. 1	25.0	
16	42.5	433	9	13.4	88	2	27.6	
17	44.3	416	10	13.0	172	4	18.7	
19	44.5	308	11	13.7	237	5	17.5	
21	45.5	358	12	16.2	401	8	15.4	
22	44.4	285	13	17.3	377	12	16.3	
23	49.7	401	14	19.5	182	15	17.6	
24	50.4	535	15	23.5	425	16	19.0	
25	51.3	522	16	27.6	262	17	22.6	
26	52.2	601	17	30.0	246	18	25.2	
27	51.2	533	18	31.4	236	19	28.6	
28	49.3	292	19	30.7	192	21	41.0	
29	47.1	269	20	31.1	413	22	42.3	
30	43.5	207	21	30.5	293	23	46.7	
31	39.1	57	22	30.6	149			
Feb. 2	29.5	248	Feb. 23	30.6	310			

Of great importance as evidence of sewage pollution were the t for Bacillus coli communis, which, as stated in previous pages, is *intestinal* parasite. Mr. Fuller found that there was little room

ubt that this germ was constantly present in the river water. He ates:

From the evidence at hand it is probable that, by taking 2 cubic centimeters r each test, this germ would be found practically without exception. Upon king 1 cubic centimeter for each test the identity of this bacillus was estab-hed in 60 per cent of the samples as shown by the results of tests, as follows:

ABLE 134.—*Result of tests (positive and negative) for Bacillus coli communis in Ohio River water at Cincinnati.*

Date.	Result.	Date.	Result.	Date.	Result.	Date.	Result.
1898.		1898.		1898.		1898.	
ar. 24	—	May 2	+	June 7	+	Aug. 1	+
25	—	3	+	9		2	
26	—	5	+	10		3	+
29	+	6	+	13		5	+
31	+	7	—	15	+	6	+
pr. 1	—	8	—	16	+	7	+
2	—	9	+	18		9	
3	—	10	+	19	+	10	+
4	—	11	+	20	+	12	+
5	+	12	+	24	+	13	+
6	+	13	—	25	+	15	+
7	—	14	+	28	+	16	+
8	+	16	+	29		18	+
9	+	17	+	30	+	19	+
10	—	18		July 1	+	20	+
11	—	19	+	2	+	22	
12	—	20		4	+	23	
13	+	21	—	7	+	24	+
14	—	22	—	8		27	+
15	+	23	+	9	+	30	
16	+	24	+	10	+	31	+
17	—	25	—	13	+	Sept. 2	+
18	+	26	+	14	+	3	+
20	+	27	+	16	+	5	—
21	—	28	+	18	+	9	+
22	+	29	—	19	+	10	
23	+	30	—	20	+	13	+
25	+	31	+	22		14	
26	—	June 1	—	23	+	15	+
27	—	2	—	25	—	16	+
28	—	3	+	27	—	17	+
29	+	4	—	28	+	18	—
30	+	6	+	29	+	21	—

TABLE 134.—*Result of tests (positive and negative) for Bacillus coli commu Ohio River water at Cincinnati*—Continued.

Date.	Result.	Date.	Result.	Date.	Result.	Date.	Re
1898.		1898.		1898.		1898.	
Sept. 22	+	Oct. 15	+	Nov. 7	+	Dec. 2	
23	+	17	—	8	+	3	
26	+	19	—	10	—	6	
27	+	20	—	11	—	8	
29	+	22	—	12	—	10	
Oct. 1	+	23	—	16	—	13	
3	—	24	+	17	+	15	
5	+	27	+	19	—	17	
7	—	28	+	20	—	20	
9	+	28	+	21	—	21	
10	+	30	+	24	—	24	
11	+	Nov. 1	+	26	+	27	
13	+	2	+	28	—	29	
14	—	4	+	30	—		

MIAMI AND LITTLE MIAMI RIVERS.

The important tributaries entering the Ohio next below S River are Miami and Little Miami rivers. They occupy the elevated portions of Ohio, and the drainage basin of the larger extends into Indiana. Taken altogether, the area drained by the rivers covers 6,950 square miles, of which 5,601 lie in Ohio. (See fig The population in the basin is 641,657, or about 92 per square Thirty cities and villages, representing a population of 242,762, water supplies. This is 91 per cent of the urban population i river basin and 44 per cent of the entire population. Fifteen o cities have been supplied with sewerage systems, all of which charge into the neighboring streams without previous purificatio

LITTLE MIAMI RIVER.

The drainage basin of the Little Miami River occupies a s wedge-shaped portion of the State of Ohio lying between the b of the Scioto and Miami rivers and fronting at the broad sout end on Ohio river. From its headwaters to its confluence wit Ohio the Little Miami traverses 94 miles and has a total fall o feet, or 7.4 feet per mile. The tributaries of the Little Miam Cæsars Creek, Todds Fork, and the East Branch of the L Miami, the latter, draining an area of 475 square miles, bein *most important.*

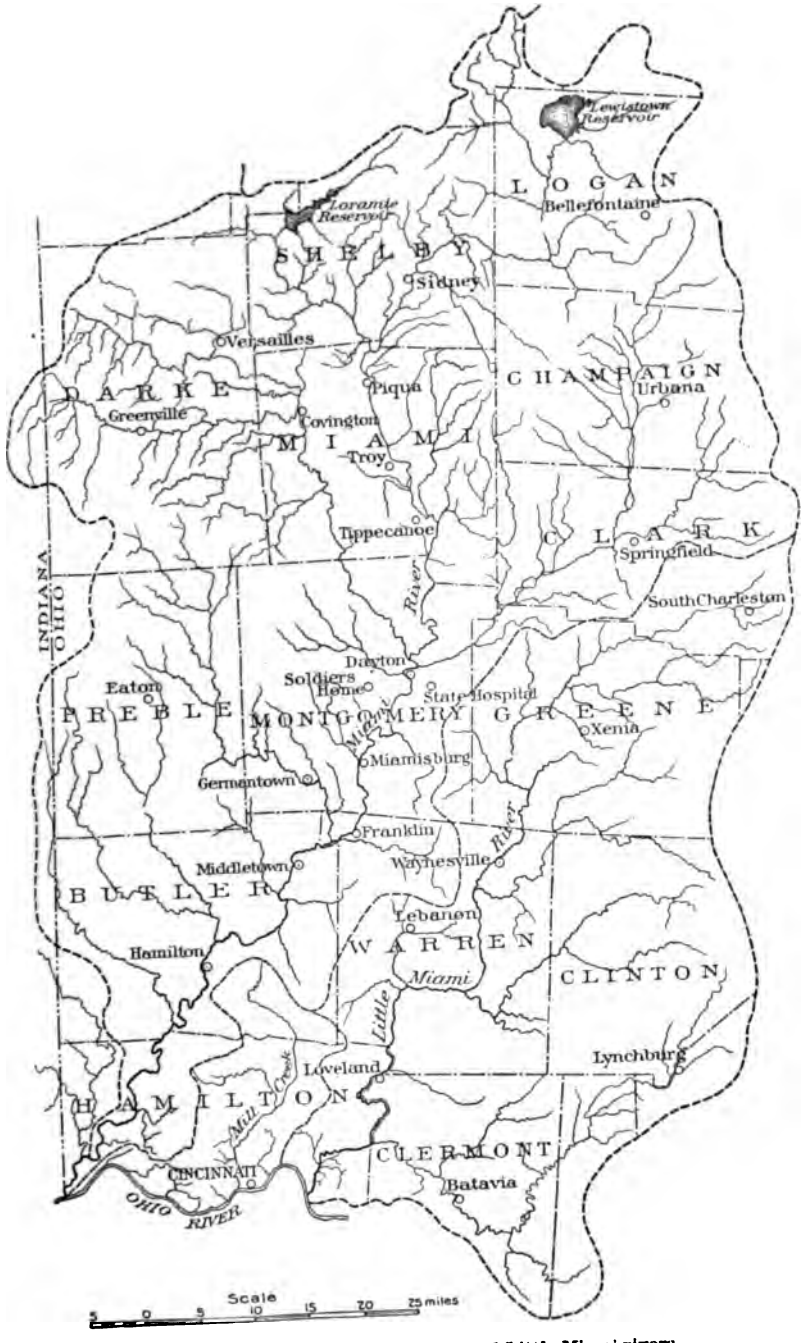


FIG. 17.—Drainage basins of Miami and Little Miami rivers.

The drainage area of the Little Miami is almost entirely devoted to farming. It is a prosperous country, with a rural population of 81,314 and an urban population of only 39,645. Sewage pollution from cities is, therefore, not so important here as in other areas which have been studied; but the run-off water from highly fertilized fields shows on analysis a large proportion of organic constituents which, if interpreted from the analysis alone, without special acquaintance with the origin of the water, would perhaps indicate a high degree of sewage pollution.

At the headwaters of the river, in Clarke County, the first important settlement is South Charleston, which has a population of 1,096. There are three short sewers in the village, and the water supply is from private wells 15 to 20 feet deep. South Charleston can therefore be considered the head of pollution upon Little Miami River. Above this place the waters are probably free from specific sewage contamination. Analyses show, however, that the organic matter is extremely high, due undoubtedly to the run-off from manured fields and rank decay of vegetable growths.

TABLE 135.—*Analyses of water from Little Miami River above South Charleston.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Rainfall during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
May 28	47	26	e a	0.200	0.138	0.042	1.24	.....	354	225.8	66.0	3,800	0.72
June 26	144	40	v	.442	.262	.090	.66	.....	390	230.4	39.8	2,200	.80
July 17	120	30	v	.522	.230	.022	.06	1.5	438	290.2	7.4	3,800	.74
Aug. 20	130	30	e	.540	.156	.018	.....	0.0	349	221.8	36.2	2,800	1.50
Oct. 18	95	23	v	.242	.080	.013	.000	0.0	362	223.2	00.0	3,400	.03
Nov. 7	100	29	v	.356	.112	.018	.000	4.0	423	266.2	00.0	3,000	.23

[a] e, earthy; v, vegetable.

The analyses set forth in the above table indicate a water of comparatively high organic content. The testimony of the free ammonia and nitrite determinations would seem to indicate a fairly high degree of sewage pollution, but this is not borne out by the remainder of the analytical statement. The water can not be regarded in any sense as normal, but it is probably free from dangerous impurities.

Below South Charleston, on Little Miami River, are Clifton and Yellow Springs, with populations of 262 and 1,371, respectively, producing no appreciable contamination of the surface drainage.

On Massicks Creek, which enters the Little Miami just above Xenia,

re situated Cedarville and Wilberforce College. At the former place strawboard works contributes the usual amount of deleterious mat-s, while at the college a part of the plumbing system is connected ith the creek.

The water which comes down to Xenia in the channel of Little iami River has received the pollution from several unimportant ettlements, but most damaging refuse comes from the strawboard orks at Cedarville. Analyses of the water (see Table 136) indicate hat, from a chemical standpoint, it is of as good quality as that found t the headwaters, above artificial pollution. The bacteriologic xamination, however, is indicative of an organic content more highly utrefactive than that which was present in the wafer above South harleston.

TABLE 136.—*Analyses of water from Little Miami above Xenia.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Rainfall during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 26	45	20	V[a]	0.220	0.032	0.028	1.17	1.1	335	223.8	18.4	44,000	0.90
May 28	80	28	V	.270	.230	.034	.70	.5	396	234.8	27.8	120,000	1.35
June 28	175	33	V	.314	.174	.038	.67	.8	423	250.8	00.0	4,800	.93
July 17	142	30	V	.794	.280	.056	.03	.7	374	200.8	00.0	1,700	.38
Aug. 22	110	43	V	.296	.090	.030	.02	.0	389	230.2	22.2	17,000	2.92
Sept. 17	50	16	V	.226	.096	.022	.06	1.4	315	235.8	00.0	3,200	.18
Oct. 18	48	35	M	.302	.136	.009	.0	.8	396	209.8	00.0	180,000	.05
Nov. 9	28	65	V	.306	.006	.010	.12	1.9	368	287.2	00.0	80,000	.23

[a] V, vegetable; M, musty.

Below Xenia the water of the Little Miami does not seem to be inferior to that above. Although the city has a population of 8,696, no sewers have been established, and the contamination of the river is not so great as might be expected from a municipality of this size. Xenia is not situated directly upon Little Miami River, but some distance up a small stream called Shawnee Run. The greatest source of pollution about Xenia is the Ohio Soldiers and Sailors' Orphans' Home, situated on Shawnee Run, southeast of Xenia. This home has an average population of 1,010, and has its own water supply and sewerage system connected with the stream.

TABLE 137.—*Analyses of water from Little Miami River below Xenia.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													
Apr. 26	45	26	v a	0.286	0.020	0.032	1.28	1.6	362	240.2	13.8	62,000	
May 28	87	32	v	.292	.310	.058	.89	4.3	418	254.4	7.0	12,000	
June 28	175	33	v	.328	.180	.036	1.04	2.2	383	221.6	32.0	5,100	
July 17	105	28	v	.314	.142	.032	.36	3.2	375	256.6	.0	1,200	
Aug. 22	90	38	v	.462	.070	.030	.00	.0	344	236.6	.0	177,000	
Sept. 17	55	17	v	.282	.078	.022	.00	1.9	388	242.4	.0	2,600	
Oct. 18	54	33	M	.212	.134	.009	.00	1.7	380	252.4	.0	34,400	
Nov. 9	35	58	v	.324	.050	.010	.10	1.6	378	281.0	.0	148,000	

a v, vegetable; M, musty.

Proceeding down the river from Xenia, the most important po of pollution discovered are Waynesville, having a population of Wilmington, on Todds Fork, inhabited by 3,613 people; Blanches on the same tributary, with 1,788 inhabitants; Lebanon, on Tu Creek, with 2,867, below which is Loveland. At this point a serie examinations has been made by the State Board of Health of Ohio, results of which are reproduced in Table 138.

TABLE 138.—*Analyses of water from Little Miami River above Loveland.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													
Apr. 24	40	18	v a	0.216	0.036	0.011	1.26	1.0	316	194.2	20.2	1,800	
May 29	430	30	e	.332	.076	.018	.52	.8	483	157.6	15.2	21,000	
June 26	250	15	m	.324	.096	.009	.40	2.2	389	238.8	12.4	1,500	
July 17	235	13	v	.254	.066	.026	.30	2.6	350	219.6	11.2	1,200	
Aug. 20	800	33	e	.312	.124	.024	.31	.0	338	128.2	20.6	8,000	
Sept. 17	103	20	e	.321	.036	.006	.00	2.8	316	210.0	.0	1,900	
Oct. 19	90	18	v	.220	.032	.006	.00	2.9	378	224.0	.0	2,100	
Nov. 9	60	26	e	.176	.022	.010	.00	2.7	343	221.2	.0	1,400	

a v, vegetable; e, earthy; m, moldy.

The analyses above set forth, when compared with those in ta 135, 136, and 137, indicate a considerable improvement in the gen character of the water. Free ammonia and nitrites, which are in ative of sewage pollution, are present in the Loveland water in sma *proportion than* in water taken higher up in the drainage area. *chlorine content*, however, maintains the same high proportion, a

idence of the contaminating influences of the municipalities mentioned.

EAST FORK OF LITTLE MIAMI.

ow Loveland enters the East Branch of Little Miami River, the pal centers of population on which are Lynchburg and Batavia. e former place a surprisingly large amount of refuse is dis- ed into the stream from a distillery and from numerous drains lead out of the town. At Batavia a public water supply has established and a number of storm sewers conduct surface age into the stream. Tables 139 and 140 are reports of analyses by the Ohio State Board of Health, which fairly indicate the cter of the water above and below Batavia.

E 139.—*Analyses of water from the East Fork of Little Miami River above Batavia.*

[Parts per million.]

	Turbidity	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity	Normal hardness.		
													Inches.
5	65	25	e[a]	0.300	0.044	0.001	0.03	2.1	270	154.8	39.0	3,200	0.65
1	95	33	v	.372	.018	.006	.14	.5	258	160.8	42.0	.....	1.49
5	70	25	v	.296	.148	.002	.12	.5	257	149.4	23.4	750	.77
0	86	25	m	.310	.118	.010	.04	.0	251	167.6	.0	2,100	1.71
1	900	28	e	.332	.096	.012	.00	.0	307	80.0	.0	40,000	1.69
9	116	23	v	.398	.060	.003	.00	1.1	238	135.4	50.2	2,300	.00
9	165	28	v	.268	.035	.003	.00	2.2	251	111.4	10.2	5,400	.00
8	70	28	v	.380	.084	.002	.08	4.6	233	121.8	6.8	1,500	.33

[a] e, earthy; v, vegetable; m, moldy.

E 140.—*Analyses of water from East Fork of Little Miami River below Batavia.*

[Parts per million.]

of	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
ll.													*Inches.*
35	60	25	e[a]	0.350	0.052	0.002	0.02	2.4	299	157.6	63.8	3,500	0.65
e 1	95	33	v	.348	.032	.007	.16	1.1	277	161.2	19.4	.....	1.49
e 27	70	28	v	.266	.146	.010	.13	.9	261	143.2	73.8	1,300	.77
30	80	25	v	.302	.136	.010	.03	.9	262	195.2	.0	2,200	1.71
21	800	28	e	.314	.104	.013	.00	.0	353	80.2	8.2	38,000	1.69
t.19	110	23	v	.326	.102	.005	.00	1.8	246	139.0	.0	1,500	.00
19	165	32	v	.234	.020	.005	.00	3.0	243	115.0	.0	6,000	.00
8	65	25	M	.276	.034	.002	.04	4.4	230	124.4	23.2	2,800	.33

[a] e, earthy; v, vegetable; M, musty.

From the confluence of the East Branch the Little Miami flows southward and empties into the Ohio just above the city of Cincinnati. From the mouth of the East Branch to the confluence of the river with the Ohio the pollution is insignificant. Analyses of the water below Linwood, a suburb of Cincinnati, make it appear preferable to any reported from the drainage area above.

TABLE 141.—*Analyses of water from Little Miami River, below Linwood.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													Inches.
Apr. 24	35	13	v[a]	0.192	0.042	0.010	0.57	2.6	308	190.6	19.4	6,100	0.45
May 29	+3,000	25	e	.638	.097	.010	.18	0.5	1,529	106.6	26.4	30,000	1.67
June 26	187	23	v	.260	.118	.006	.08	3.2	345	212.8	3.0	3,000	.00
July 19	+3,000	25	e	.658	.134	.014	.10	1.3	1,913	127.6	25.2	43,000	1.53
Aug. 20	1,000	28	e	.246	.068	.022	.10	0.0	352	108.2	.0	7,300	.86
Sept. 18	120	23	e	.370	.076	.006	.00	3.4	326	205.8	.0	1,300	.00
Oct. 13	200	32	e	.302	.064	.006	.00	3.1	356	161.6	.0	3,900	[b]1.12
Nov. 8	40	25	e	.202	.026	.000	.04	4.1	302	229.2	8.6	1,200	.27

[a] v, vegetable; e, earthy. [b] Storms one week previous.

The drainage basin of Little Miami River is without special interest from the standpoint of water pollution. As has already been observed the urban population is comparatively small and the sewage it contributes to the river does not seem to have very marked effects on the water. The analyses show a high content of organic matter from the headwaters down, and while the water may not have been much damaged it is certainly not so desirable for public use as some of the purer waters found in other parts of the State. It can hardly be said, however, that Little Miami River has suffered greatly from city or manufacturing refuse, and it is more than likely that if all sewage were removed from the stream and its tributaries the natural drainage of an area so highly fertilized would so change the character of the run-off water that it would be hardly acceptable for city water-supply purposes without filtration. The other resources vested in the natural waters of this area do not appear to be damaged appreciably.

MIAMI RIVER.

Entering Ohio below Cincinnati, the Miami River drains a basin to the north thickly dotted over with towns and cities. The main stream is formed at Dayton by the confluence of the Upper Miami, Stillwater, and Mad rivers, which have drainage areas of 1,158, 645, *and 653* square miles, respectively. From Dayton to the mouth the river flows in a somewhat winding course to the southwest. From its

waters in Lewistown reservoir, in the extreme northern part of drainage area, to its mouth the Miami has a length of 163 miles.

NORMAL WATER IN THE MIAMI BASIN.

a drainage area like that of the Miami it is difficult to secure ples of normal water. The run-off from land given over to agri- ure is seldom, if ever, of a quality which approaches the normal closely. There appear, however, in the report of the Ohio State rd of Health for 1901 three series of analyses of water taken from ams which, so far as is known, bear no direct sewage pollution. se streams are Mad River above Urbana, Buck Creek, a tributary fad River, above Springfield, and Greenville Creek above Green- e City. The population upon the drainage area of these streams ve the points named is of the usual agricultural nature, and the ution of the run-off water is probably confined to the drainage of ured fields.

he analyses made by the Ohio State Board of Health are set forth ow in Table 142.

TABLE 142.—*Analyses of nearly normal waters in the Miami River Basin.*

BUCK CREEK ABOVE SPRINGFIELD.

[Parts per million.]

of ge n.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
0.													*Inches.*
.16	.....	10	None	0.104	0.016	0.005	0.84	0.4	407	242.0	2.98	385	0.54
24	25	10	v[a]	.328	.032	.010	1.14	.3	431	244.0	27.20	1,200	1.49
20	32	23	e	.096	.036	.008	.83	.2	438	268.0	12.00	375	.00
10	90	15	e	.176	.028	.010	1.06	.4	463	260.2	30.00	800	.33
9	57	17	v	.134	.042	.010	1.64	.0	384	227.6	29.00	400	.00
5	60	13	v	.206	.044	.011	1.46	.0	386	239.4	1.80	600	.40
3	35	15	v	.112	.022	.002	1.03	.4	425	219.4	3.00	1,200	1.03
3	16	17	None	.078	.019	.014	2.12	.5	399	249.4	13.20	1,000	.23

MAD RIVER ABOVE URBANA.

0.													*Inches.*
19	100	32	e	0.258	0.014	0.010	1.87	0.0	497	229.0	60.6	12,000	1.42
24	17	12	e	.104	.040	.010	.82	.5	347	265.4	3.0	700	.86
20	70	21	v	.170	.050	.009	.83	.0	434	271.8	26.8	1,700	.00
9	100	18	v	.220	.060	.017	.64	.2	410	266.2	11.4	2,200	1.05
9	95	22	v	.182	.054	.016	1.04	.2	396	250.4	.0	3,300	.11
5	165	28	e	.380	.032	.007	.83	.0	438	230.4	21.0	5,900	.25
3	90	18	v	.130	.032	.006	1.26	1.0	462	260.2	1.6	4,000	1.31
3	28	20	None	.086	.019	.005	.00	.0	390	251.4	1.4	2,200	.20

[a] v, vegetable; e, earthy.

TABLE 142.—*Analyses of nearly normal waters in the Miami River Basin*—Cont'd.

GREENVILLE CREEK ABOVE GREENVILLE.

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1900.													*Inches.*
Apr. 17	28	20	v[a]	0.188	0.060	0.016	3.44	0.2	449	217.8	83.0	3,300	0.60
May 22	24	28	v	.211	.094	.038	2.09	.0	380	226.2	40.0	1,100	1.22
June 18	28	25	v	.184	.084	.014	.55	.6	467	278.4	31.0	1,300	.00
July 10	70	27	v	.214	.060	.020	.44	.4	369	280.0	.0	1,100	.52
Aug. 7	65	22	v	.268	.134	.011	.00	2.7	421	255.4	3.2	2,000	1.68
Sept. 3	55	23	v	.186	.096	.010	.00	1.0	413	269.0	.0	4,700	.00
Oct. 1	130	42	v	.272	.063	.024	2.12	.0	432	189.6	35.0	19,000	3.22
Nov. 1	28	20	e	.164	.019	.002	.00	1.5	472	274.0	26.6	6,400	.35

[a] v, vegetable; e, earthy.

Inspection of the above table readily shows that the water in Buck Creek above Springfield is decidedly the best. Throughout the whole table the content of organic matter indicated is comparatively low and maintains a fair degree of uniformity. In the Buck Creek analyses the free ammonia, nitrites, and chlorine are much lower than in any analyses heretofore presented for this area. There is the same steadiness in the total residue column that was evidenced in the Little Miami examinations. Turbidity and bacteria per cubic centimeter are comparatively uniform in spite of the fact that there were wide fluctuations in the precipitation during the ten days previous to each examination.

Turning now to the three affluents of the Miami, let us consider the conditions existing within the drainage areas of each.

MAD RIVER.

Mad River has its origin in Logan County and flows with a general southwesterly trend to Dayton. The city of Urbana, with 6,808 inhabitants, lies at the head of sewage pollution. A water supply has been established in Urbana, but the sewerage system is confined to a few private lines of pipe. The principal source of pollution, however, is the highly contaminated run-off occasioned by the storage of polluting material in vaults and cesspools, rarely cleaned, but allowed to filter into the ground. The most important point of pollution is the city of Springfield, which has a population of 38,253.

Water and sewerage systems have been established, but the latter is said to be very poor, and only about 20 per cent of the population has access to it. The most flagrant source of pollution from Springfield is the method of disposing of garbage, night soil, and dead animals. These are dumped promiscuously into the river or buried on or near the *banks. There is* also considerable pollution from various industries. *There are* available the results of analyses of series of samples

ı Mad River above and below Urbana, above and below , and above Dayton; also from Buck Creek, above Spring- reports of the first and last named have already been ıble 142.

lowing table the average results of monthly determinations 'e-named places are set forth:

TABLE 143.—*Analyses of water from Mad River.*

[Averages for eight monthly examinations, in parts per million.]

ollection.	Turbidity.	Color.	Nitrogen as—					Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.		Alkalinity.	Normal hardness.	
.....	80	21	0.191	0.038	0.010	0.91	0.2	422	253.1	14.5	4,000
.....	115	47	.608	.039	.060	.47	1.2	456	278.7	16.5	160,000
eld.....	80	27	.260	.076	.028	.48	.5	431	272.1	12.1	9,500
ıld (Buck Creek)	40	15	.154	.030	.009	1.34	.3	417	243.8	18.2	738
ıld	75	24	.270	.201	.042	.00	3.3	435	270.6	9.2	31,000
.....	80	20	.194	.033	.011	1.32	2.8	417	254.8	14.0	6,750

ı of the above analyses shows the usual unmistakable evi- ontamination of the river from the two principal polluting the improvement of the water as it flows from one of these e other. The character of the water above Urbana on Mad ıbove Springfield on Buck Creek has already been discussed. ır passes by Urbana there is a notable increase in the content natter as well as in turbidity and in the number of bacteria entimeter. From Urbana to Springfield the water shows improvement, but is again changed in passing the city of , while the analyses made of samples taken above Dayton the water has so far improved as to be, from a chemical at least, almost as good as it appears above Urbana. The mples show the character of the water contributed to the em by Mad River.

UPPER MIAMI RIVER.

iami River has its origin in Lewistown reservoir and flows somewhat circuitous route to join the Stillwater and Mad ıyton. The head of pollution upon the Upper Miami is Belle- village of 6,649 inhabitants, supplied with water and a m of storm sewers. The principal pollution from this point the drainage of a few plumbing systems into the storm refuse from slaughterhouses, and the pollution of run-off ıgh putrescible material stored in the ground. A few insti- ch as the Logan County Infirmary, Logan County Childrens' the Shelby County Childrens' Home and Infirmary, con- re direct sewage pollution to the river than any of the small *ıated along the* stream. The village of Sidney, having a

population of 5,688, has a water supply and has just introduced a system of sewers. These, together with a brewery and a tannery and various other incidental contaminating points, produce considerable damage to the river.

Next below Sidney is Piqua, having a population of 12,172. The public water supply at this point is not used for domestic purposes. A separate system of sewers, to which about 30 per cent of the people have access, has been established. These sewers empty directly into the Miami River. In the town are located strawboard works, oil mills, breweries, and several large slaughterhouses, and the effluent from these and the sewers is the occasion of serious nuisances at times.

Below Piqua is Troy, containing 5,581 inhabitants, and still farther down is Tippecanoe City, with 1,703. Both places have public water supplies and a few short, combined sewers, to which a small proportion of the people have access. Garbage and night soil are dumped along the river and into the Miami and Erie Canal, which flows along the river bank. In addition to the pollution from sewers, the river receives the refuse from three distilleries, two breweries, and several large slaughterhouses.

Chemical examinations of the water of the Upper Miami have been made above and below the cities of Sidney, Piqua, and Troy, and above Dayton, and the averages of the eight monthly analyses of samples taken at each point appear in the following table:

TABLE 144.—*Analyses of water from Upper Miami.*

[Averages of eight monthly examinations, in parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Sidney	60	23	0.295	0.066	0.009	0.52	0.7	404	219.8	33.3	1,900
Below Sidney	45	24	.289	.074	.014	.57	2.3	379	223.9	25.9	4,700
Above Piqua	200	28	.400	.077	.010	.65	1.2	484	200.6	31.9	11,000
Below Piqua	240	27	.374	.048	.027	.90	3.4	468	208.9	25.0	22,500
Above Troy	55	26	.344	.105	.018	.54	2.4	388	214.7	27.2	5,400
Below Troy	35	24	.378	.112	.019	.61	3.2	364	221.9	20.4	52,000
Above Dayton	100	25	.307	.049	.013	.68	1.5	407	220.9	24.9	5,600

The effect of sewage on the Miami River above Dayton, as indicated by the above analyses, is so obvious as hardly to merit discussion. The same general features, repeatedly observed in the discussion of drainage areas in previous pages, occur here. As the Miami enters the city of Dayton, the water, from a chemical standpoint, is only a little inferior to that in the same stream above Sidney.

STILLWATER RIVER.

Stillwater River, entering the Miami at Dayton, drains the country to the northwest, comprising large areas in Darke and Miami coun-

ies. The principal source of pollution along the entire length of Stillwater River is the city of Greenville, which has a population of 6,501. At this place water and sewerage systems have been installed, the latter being one of the best in the drainage area. In addition to the contaminating matter carried into the former from the sewers, here is the polluted surface drainage from that part of the town which has not yet been connected with the sewerage system.

In the drainage area of the Stillwater there are several institutions which furnish the usual amount of contamination. The villages of Versailles and Covington, containing 1,478 and 1,791 inhabitants, respectively, are the only remaining points within the watershed that are important from the standpoint of stream pollution.

Three sampling points were selected by the Ohio State Board of Health as a basis for their investigation into the character of the water in Stillwater River. These are located above and below Greenville, on Greenville Creek, and above Dayton.

TABLE 145.—*Analyses of water from Stillwater River.*

[Averages of eight monthly examinations, in parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Greenville	55	26	0.211	0.072	0.017	1.08	0.8	425	248.8	27.3	4,900
Below Greenville	70	27	.274	.091	.022	1.17	2.6	475	251.7	85.4	13,500
Above Dayton	80	23	.251	.041	.009	2.02	.9	380	218.9	8.3	45,500

Examination of the results above set forth shows nothing of an uncommon nature. Above Greenville, as has been already shown in the consideration of normal waters in the Miami drainage area, there is little evidence of specific sewage contamination. Below Greenville there is, as might be expected, an increase of those ingredients whose presence is generally accepted as an indication of pollution, but the amount of this increase is not so great as might be expected when all the circumstances are considered. The analyses of samples taken above Dayton indicate the usual improvement in a water after it has flowed beyond the point of contamination for a considerable distance.

The city of Dayton has a population of 85,333, the largest on the drainage area of the Miami. It is provided with a water supply and a sewerage system, to which 30 per cent of the people have access. Garbage is burned in a crematory and night soil is disposed of upon the farms outside the city, so that the pollution of the river is confined to the affluents from the sewerage system and the refuse turned into the stream by industrial plants, which consist of breweries, slaughter and packing houses, oil mills, soap works, and paper and strawboard manufactories.

MIAMI RIVER BELOW DAYTON.

Below the city of Dayton, on the Miami, are located the National Soldiers' Home and the Dayton State hospital. The combined population of these two institutions is 5,810. Both are provided with sanitary sewers and improved systems of plumbing, which discharge directly into the river. This is the largest center of pollution in the whole drainage area, greater, in fact, than the city of Dayton itself. Continuing down the river from the two institutions above mentioned the next important point is Miamisburg, which has a population of 3,941. Industrial pollution seems to be the most important at this village, which has no water or sewerage system.

The village of Franklin, a few miles below Miamisburg, is inhabited by 2,724 persons and is supplied with water and a small system of sewerage. In addition to the contamination afforded by the latter a large proportion of the garbage of the town is dumped into the river and some of the industrial plants, such as paper mills and slaughter houses, pour their refuse into the stream.

Middletown is situated a few miles below Franklin, on the east bank of Miami River. It has an excellent water supply and sewerage system, through which the sewage of about 2,000 persons is carried directly into the river. The waste from a large number of manufacturing establishments also finds its way there. Among these are gas works, breweries, malt houses, etc.

A few miles below Middletown is the city of Hamilton, through the center of which Miami River passes. Hamilton has a population of 23,914, a good water supply, and an extensive system of sanitary and storm sewers. In addition to the polluting material poured into the river by these sewers, it receives the refuse from a large and varied assortment of industries.

Below Hamilton there is little of interest until the mouth of the river is reached.

Sampling points selected by the Ohio State Board of Health are below Dayton, above and below Middletown, above and below Hamilton, and below Cleves.

TABLE 146.—*Analyses of water from Miami River.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Below Dayton	81	25	0.309	0.067	0.021	1.99	4.2	407	220.9	24.9	65,000
Above Middletown	215	27	.261	.045	.015	.46	3.3	432	212.2	18.5	19,000
Below Middletown	257	29	.340	.047	.022	.51	5.3	461	220.5	15.4	43,000
Above Hamilton	1,820	28	.345	.058	.012	.75	3.1	626	188.7	13.9	25,500
Below Hamilton	1,300	26	.361	.072	.018	.57	4.7	551	199.4	14.5	33,000
Below Cleves	2,250	26	.406	.056	.012	.63	3.9	813	191.7	12.4	7,000

The character of the water contributed to the Ohio system by the Miami is not all that could be desired, nor indeed as good as might easily be furnished. In the course of the river from Dayton to its mouth the changes in the organic constituents of the water are not exceedingly sharp. The undesirable condition of the run-off at Dayton is maintained steadily throughout the remainder of the course. The sewage of Dayton and the two institutions just below it is apparent in the report of the analyses of samples taken above Middletown. The additional polluting material poured in from Middletown is perfectly evident, and by the time the water reaches Hamilton only a very small improvement can be noted. The water contributed to the system by the three main affluents above Dayton seems to be far superior to that which flows by Cleves into Ohio River.

OHIO RIVER AT LOUISVILLE.

During the years 1895, 1896, and 1897 extensive investigations were carried on by the Louisville Water Company to determine the character of the water in Ohio River opposite that city. Mr. George W. Fuller was placed in charge of this work, and in the year 1898 submitted an exhaustive report on the purification of the water of Ohio River. Daily examinations of the water of Ohio River were made from October 16, 1895, to July 24, 1897, the reports of which will not be given here in full, but attention will be directed to several important determinations.

Relative to the drainage area and general hydrographic conditions Mr. Fuller writes as follows:

> The water of the Ohio River at Louisville varies widely from time to time in its composition. This variation is caused by a number of factors, among which are the following:
>
> 1. The size and varying geological formation of the watershed.
> 2. The number of comparatively large tributaries which drain areas of distinctly unlike geological character.
> 3. The amount of precipitation (rain and snow).
> 4. The distribution of the precipitation over the watershed.
> 5. The condition of the soil at the beginning of heavy rain storms.
> 6. The amount and rate of precipitation during single storms.
> 7. The stage of the river.
> 8. The velocity of flow of the river.
> 9. Agitation of the water in the river due to wind storms, etc.
>
> The total population resident on this watershed above Louisville is estimated at 4,500,000, of which 1,575,000 is contained in 220 towns and cities, according to the census of 1890, increased 15 per cent for the six years of the present decade. The nearest city discharging sewage into the water which passes this pumping station is Madison, Ind., situated about 50 miles above Louisville, with a population of about 12,000. The next city is Frankfort, Ky., situated on the Kentucky River, 67 miles from its mouth. This city has a population of about 10,000. The Kentucky River joins the Ohio about 57 miles above Louisville. The nearest large center of population discharging sewage into this water supply is at Cin-

cinnati, Ohio. Opposite this city are the cities of Newport and Covington, Ky. Their aggregate population (three cities) is about 420,000, and they are distant above Louisville about 150 miles by river.

The rises and floods in the Ohio River, with their associated factors, produce wide and rapidly changing variations in the composition of the river water. Owing to the fact that the composition of the river water is a prominent factor in the cost of purification, analyses were made practically every day during these tests of the water before its application to the systems of purification. Before giving attention to the results of analyses, however, the question of frequency and depth of freshets or floods is to be considered.[a]

TABLE 147.—*Amount of carbonic acid gas (carbon dioxide) dissolved in the Ohio River water at Louisville.*

[Parts per million.]

Date.	Carbonic acid gas.	Date.	Carbonic acid gas.	Date.	Carbonic acid gas.	Date.	Carbonic acid gas.
1896.		1897.		1897.		1897.	
June 18	[b]30.8	Mar. 24	44.9	May 7	57.4	June 18	82.7
22	[b]26.4	25	41.9	8	110.6	19	106.3
24	[b]27.7	26	36.5	9	66.7	20	100.3
27	[b]29.7	27	47.0	10	72.1	21	100.3
July 3	[b]30.6	29	56.6	13	65.2	22	100.3
8	[b]21.1	30	80.0	14	76.6	23	107.4
Nov. 28	83.0	Apr. 1	53.6	15	50.8	24	100.3
Dec. 10	98.0	2	59.0	18	67.3	25	105.6
1897.		3	53.5	19	71.8	26	113.7
Feb. 16	80.4	7	79.6	21	88.7	27	120.0
Mar. 2	63.4	8	46.0	22	95.9	28	92.1
3	59.0	9	91.0	23	94.3	30	105.9
4	67.8	10	80.0	26	80.2	July 1	93.9
5	49.3	12	65.0	27	80.0	2	75.3
6	47.6	13	44.0	28	107.3	3	73.1
7	51.4	14	75.7	29	101.6	6	100.4
11	99.5	15	88.3	June 1	66.6	7	106.1
12	88.0	16	50.2	2	90.5	8	99.9
13	122.4	21	41.2	4	82.7	12	71.8
15	45.8	22	42.7	7	89.0	15	47.0
16	33.4	23	43.0	10	133.0	16	28.8
19	38.8	25	55.0	11	107.6	17	49.4
20	42.6	27	94.9	15	98.8		
22	46.4	29	85.9	16	103.3		
23	40.4	May 4	86.8	17	107.6		

[a] Report on the investigations into the purification of the Ohio River water at Louisville, Ky., made to the president and directors of the Louisville Water Company by George W. Fuller, 1898.

[b] The results of June and July, 1896, were obtained by the Pettenkoffer method, without the *Trillich modification*, and are probably much too low

e normal hardness or amount of incrusting constituents in the River water is set forth in the following table:

TABLE 148.—*Normal hardness of water of Ohio River at Louisville.*

[Parts per million.]

ıte.	Normal hardness.	Date.	Normal hardness.	Date.	Normal hardness.	Date.	Normal hardness.
95.		1897.		1897.		1897.	
9–11	43.9	Mar. 15	14.0	Apr. 20–21	15.5	May 28–29	16.8
96.		16	20.5	21–22	17.5	31	.....
6	43.0	17	24.6	22	12.0	June 1	17.0
14	33.8	18	36.7	22–23	14.6	2–3	17.6
22	40.1	19	16.7	23–24	14.3	4–5	23.5
29	41.1	20	22.0	27	12.7	7–8	22.5
11	44.0	22	12.0	28	17.0	9–10	23.8
18	30.0	23	9.6	29	32.0	11–12	28.8
30	35.0	24	10.8	29–30	21.7	21	28.8
97.		25	10.0	30	.....	22	31.0
17	18.7	26	13.9	May 1	20.0	23	27.8
22	24.7	29	12.8	4	23.0	24	21.9
23	17.2	30	33.3	5	17.0	25	19.0
24	21.2	Apr. 1	29.1	6–7	15.5	27	17.5
25	16.1	2–3	18.2	8–9	15.8	28	25.5
26	8.0	3–4	11.0	13	16.1	29–30	20.0
1	15.8	5	29.9	14	23.2	July 2	20.0
2	10.0	6	23.4	15	11.3	6	20.9
3	8.0	6–7	30.0	17–19	9.0	7	27.0
4	12.0	8	19.8	19–20	10.8	9–10	11.0
5	25.3	9	14.2	21	11.9	12–13	12.0
6	34.6	9–10	13.3	21–23	15.9	14–15	14.8
7	16.0	11	9.0	23–24	10.2	16	14.0
9	23.4	12	12.7	25	20.2	17–18	12.3
10	17.9	13–14	16.0	25–26	14.5	19–20	24.2
11	30.0	14–15	20.0	27	16.7	21–22	24.2
12	33.0	15–16	18.1	27–28	19.3	23–24	43.8

n interesting investigation into the amount and corrosive effect lissolved carbon dioxide in the river water brought out the fact t such determinations are of more importance than had been pre-ısly supposed. The observation is made in Mr. Fuller's report t at times the weight of the dissolved carbon dioxide in the river er equals and even exceeds the weight of all dissolved solids. The ɔunt of carbon dioxide found in the water at each examination is down in Table 147.

SUMMARY.

In the foregoing pages we have reviewed the important and read available records of water examinations which have been carried in this country, except those now being prosecuted in connection w the Chicago Drainage Canal and Illinois River. It is apparent fr this review that the pollution of natural waters follows social mun pal progress. Those rivers which remain in their normal condition situated in areas that have not been penetrated to any extent by growth of American institutions. Nearly all important streams h been damaged and their normal resources diminished. The quest may be asked: Is not the damage done to these streams by the sew of cities and by industrial plants merely a part of the compensat which we should willingly pay for the advantages that we have gai through the establishment of those polluting influences? Undoubte to a certain degree; but the fact still remains that in most ca when such damage is carried beyond a certain point it must be regard as needless and unwarranted.

Water pollution is inevitable wherever the human race is cluste together in large numbers, but by the application of the methods sewage disposal which modern science has made available, and the exercise of an ordinary amount of municipal decency, such pol tion can be so restricted that it will result in the destruction of on one or two of the resources which are vested in natural waters.

There is no doubt that the run-off water from a thickly settl country is likely to be dangerous for domestic uses unless it is filtere and the current methods of sewage disposal, while theoretically pe fect, are practically not sufficiently so to warrant us in using t so-called purified effluents as we would use the run-off from an uni habited region. Yet, if proper precautions are taken and the sa attention is paid to sewage disposal that is ordinarily given to oth departments of municipal affairs, every community will be the rich and the tremendous waste of natural resources which is now taki place will ultimately be restricted to that which is necessary.

INDEX.

Page.

io, rainfall at 131
I., water from Blackstone River at, analyses of 68
id ammonia, occurrence of 24
urrence of, in surface waters .. 20
r Basin, general features of .. 119-120
f 119-120
ion in 121-122
ation of 120-121
y River, water from, analyses of 122, 123, 124
Ohio, water from Mahoning River near, analyses of 131, 132
a, albuminoid, occurrence of 24
a, free, occurrence of 24-25
oosuc River, N. H., power utilized on 71
s, normal water 29
ıal water from Massachusetts 23, 25, 118
rom Ohio Basin 118
n Miami Basin 177-178
ıted water 29
rom Massachusetts 25
r water. *See* names of streams.
s, sanitary, discussion of 22-33
r, Mass., ground water from, analysis of 38
or from Shawsheen River at, analysis of 39
Creek, Ohio, water from, analysis of 142
nham reservoir, Mass., water from, analysis of 50
l reservoir, Mass., water from, analyses of 37
ot River, N. H., power utilized on. 71
; River, Mass., pollution of 44-45
er from, analysis of 45
Mass, water from, analysis of 74
er from Millers River near, analyses of 75
Lake, Mass., water from, analysis of 100
a, occurrence of, in surface waters 19
Mass., water from Ware River near, analysis of 80, 82
Water Company, water from reservoir of, analysis of 81
s Junction, Mass., water from Swift River at, analysis of 83
, Ohio, water from East Fork of Little Miami River near, analyses of 175
Brook, Mass., power utilized on.. 35

Page.

Bedford, Mass., water from Shawsheen River at, analysis of 39
Bellefontaine, Ohio, pollution near 179
Billerica, Mass., water from Concord River near, analyses of 45
Black Fork, Ohio, water from, analyses of 138, 139
Black River, Vt., power utilized on 71
Blackstone Basin, R. I., general features of 60
map of 61
normal water in, analyses of 62
pollution in 63-68
population of 60
Blackstone River, water from, analyses of 63, 65, 66, 67, 68
Boilers, essential qualities of water used in 14
Brilliant, Pa., water from Allegheny River at, analyses of 122, 123
Brookfield, Mass., water from, analysis of. 83
Buck Creek, Ohio, water from, analyses of 177, 179
Burnside, Conn., water from Hockanum River at, analyses of 91
Cambridge, Ohio, water from Wills Creek near, analyses of 149
Campton, N. H., water from Pemigewasset River at, analysis of 55
Canal Dover, Ohio, water from Tuscarawas River near, analysis of 145
Canton, Ohio, water from Nimishillen Creek near, analyses of 144
Castleman River, Pa., water from, analysis of 127
Catlettsburg, Ky., rainfall at 164
Cedarville, Ohio, pollution at 173
Chelmsford, Mass., ground water from, analysis of 38
Chester, Mass., water from, analysis of.. 87
Chicopee River, Mass., map of basin of.. 78
pollution of 77-85
power utilized on 71
water from, analysis of 85
Chlorine, occurrence of 26-29
Chlorine map of Massachusetts and Connecticut 28
Cincinnati, Ohio, floods at, duration, intensity, etc., of 165
rainfall at 164
Circleville, Ohio, water from Scioto River at, analyses of 162
Cleves, Ohio, water from Miami River near, analysis of 182

Page.

Clinton, Mass., pollution at 48
Coachlace Brook, Mass., water from, analysis of 49
Cohas Brook, N. H., power utilized on ... 35
Colerain, Mass., water from Deerfield River near, analyses of 77
Color, determination of 23
Columbus, Ohio, water from Olentangy and Scioto rivers at, analyses of 160
Concord, Mass., ground water from, analysis of 38
water from Concord River at, analyses of 45
from Sudbury River near, analyses of 43
Concord River, Mass., power utilized on. 35
water from, analyses of 45
Concord River Basin, character of 39
map of 39
Connecticut, chlorine map of Massachusetts and 28
court decisions in 107-112
Connecticut River, fall of 70
flow of 71-72
general features of basin of 68-71
map of basin of 69
pollution of 94-97
water from, analyses of 95, 96, 97
water power in basin of 71
Contoocook River, N. H., power utilized on 35
Coshocton, Ohio, water from Tuscarawas and Muskingum rivers and Walhoning Creek near, analyses of 148
Court decisions in Connecticut 107-112
Crystal Lake, Mass., water from, analysis of 37
Dalton, Mass., water from Egypt Brook at, analysis of 100
Danbury, Conn., pollution from, decision of court on 107-108
water from, analysis of 100
Dayton, Ohio, pollution at 181
water from Mad River near, analyses of 179
from Miami River near, analyses of 180, 182
from Stillwater River near, analysis of 181
Deerfield River, Mass., pollution and character of water of 76-77
power utilized on 71
water of, analyses of 77
Delaware, Ohio, water from Olentangy River near, analyses of 159
Delaware River, cities and towns contributing polluting substances to 114
map of basin of 113
turbidity of, at Trenton 116
water from, analyses of 115
Dennison, Ohio, water from Stillwater Creek near, analysis of 147
Derby, Conn., water from Housatonic River at, analyses of 106

Page.

Disease germs, occurrence of, in surface waters 21
Dracut, Mass., ground water from, analysis of 38
Drinking water, essential qualities of 15-16
Drown, T. M., reference to 20
Egypt Brook, Mass., water from, analysis of 100
Enfield, Mass., water from Swift River at, analysis of 88
Etna, Pa., water from Allegheny River at, analysis of 124
Falls Village, Conn., water from Housatonic River at, analyses of 105
Farm Brook, Conn., water from, analysis of 100
Farmington River, Conn., character of .. 94
power utilized on 71
Fisheries, essential quality of water of ... 15
Fitchburg, Mass., water from North Branch of Nashua River near, analyses of 50, 51
Florida, Mass., water from Deerfield River near, analysis of 77
Framingham, Mass., ground water from, analysis of 38
Framingham reservoir, Mass., water from, analysis of 37
Franklin, Ohio, pollution at 182
Free ammonia, occurrence of 24-25
Fuller, G. W., quoted 163-170, 183-185
work of 162
Galion, Ohio, water from Olentangy River near, analyses of 158
Gardner, Mass., water from, analysis of. 74
Germs, disease, occurrence of, in surface waters 21
Goodspeed Landing, Conn., water from Connecticut River at, analyses of 97
Granville, Mass., water from, analysis of. 87
Great Barrington, Mass., water from Green River at, analysis of... 100
Green River, Mass., water from, analysis of 100
Greenville, Ohio, pollution at 181
water from Greenville Creek near, analyses of 178
from Stillwater River near, analyses of 181
Greenville Creek, Ohio, water from, analyses of 178
Greenwich, Mass., water from Swift River at, analyses of 88
Groton, Mass., water from Nashua River at, analysis of 53
Hamilton, Ohio, water from Miami River near, analysis of 182
Hardness, discussion of 30-31
Hartford, Conn., water from Park River at, analyses of 92
Haverhill, Mass., water from Merrimac River near, analyses of 59
Haynes reservoir, Mass., water from, analysis of 37
Highways, essential quality of water used for 18

Page.

Hinsdale, Mass., water from East Branch Housatonic River at, analyses of ... 100
Hockanum River, Conn., pollution of 89-91
power utilized on ... 71
water from, analyses of ... 90, 91
Holden, Mass., water from Quinepoxet River at, analyses of ... 48
Holyoke, Mass., flow of Connecticut River at ... 71-72
Housatonic River, fall of ... 98
map of basin of ... 98
natural resources of ... 98-100
normal water in basin of ... 100
pollution in basin of ... 101-107
water from, analyses of ... 101, 102, 103, 104, 105, 106
Huntington, Mass., water from, analysis of ... 87
Ice industry in Merrimac River Basin ... 35
Ice supply, essential qualities of water used as ... 15
Impurities in natural waters ... 16
Indian Creek, Pa., water from, analyses of ... 127
Irrigation, essential qualities of water used for ... 15
Israels River, N. H., power utilized on ... 71
Jerome Fork, Ohio, drainage area of ... 140
Kenton, Ohio, water from Scioto River near, analyses of ... 155
Kettle Brook, Mass., water from, analyses of ... 62
Killbuck Creek, Ohio, water from, analyses of ... 142
Lake. *See* next word of name.
Lancaster, Mass., water from North Branch of Nashua River near, analyses of ... 52
water from South Branch of Nashua River near, analyses of ... 49
Laurel Hill Creek, Pa., water from, analysis of ... 127
Lawrence, Mass., effluent from filter at, analyses of ... 58
Merrimac River at, discharge of ... 36
water from Merrimac River near, analyses of ... 57
Leominster, Mass., water from Monoosnoc Brook at, analysis of ... 51
Leyden, Mass., water from Deerfield River near, analysis of ... 77
Licking Creek, Ohio, pollution and analyses of water from ... 149-151
Linwood, Ohio, water from Little Miami River near, analyses of ... 176
Little Miami River, Ohio, pollution and analyses of water of ... 170-176
Little River, Conn., power utilized on ... 71
Little Scioto River, water from, analyses of ... 156
Louisville, Ohio River at, character of water of ... 183-185
Loveland, Ohio, water from Little Miami River near, analyses of ... 174

Page.

Lowell, Mass., ground water from, analysis of ... 38
typhoid-fever epidemic at ... 56
water from Merrimac River near, analyses of ... 56
Ludlow, Mass., water from Chicopee River near, analysis of ... 85
Lynchburg, Ohio, pollution at ... 175
Lynde Brook reservoir, Mass., water from, analyses of ... 62
McConnelsville, Ohio, water from Muskingum River near, analyses of ... 152
Mad River, Ohio, pollution of ... 178-179
water from, analyses of ... 177, 179
Mahoning River, map of basin of ... 130
natural resources of basin of ... 129-130
water from, analyses of ... 131, 132, 133, 134, 135
Manchester, Conn., water from reservoir at, analyses of ... 90
Manchester, N. H., pollution at ... 55
Mansfield, Ohio, water from Rocky Fork near, analyses of ... 140
Manufacturing, essential qualities of water used for ... 14
Marietta, Ohio, rainfall at ... 164
water from Muskingum River near, analyses of ... 152
Marion, Ohio, water from Little Scioto River near, analyses of ... 156
Mascomy River, N. H., power utilized on 71
Massachusetts, chlorine map of Connecticut and ... 28
normal water from, analysis of ... 23, 25, 118
polluted water from, analysis of ... 25
Massillon, Ohio, water from Tuscarawas River near, analyses of ... 143
Merrimac River, discharge of ... 36
pollution of ... 55-59
water from, analyses of ... 55, 56, 57, 58, 59
Merrimac River Basin, discharge measurements in ... 36
general features of ... 33-36
ice industry in ... 35
map of ... 34
normal water in, analyses of ... 37-38
pollution in ... 38
power in ... 33-35
Methuen, Mass., ground water from, analysis of ... 38
Miami River, map of basin of ... 171
normal and polluted waters in basin of ... 176-183
pollution of, and analyses of water from ... 182-183
water from, analyses of ... 180, 182
water from, near Middletown, Ohio, analysis of ... 182
Mill River, Mass., power utilized on ... 71
Mill Run, Pa., water from, analyses of .. 127
Millers River, Mass., general features of basin of ... 73-75
map of basin of ... 73
normal water of, analyses of ... 74
pollution of ... 75-76

Page.

Millers River, Mass., power utilized on.. 71
water from, analyses of..... 75, 76
Millvale, Pa., water from Allegheny River at, analysis of..... 124
Millville, Mass., water from Blackstone River near, analyses of..... 67
Mine Falls, N. H., water from Nashua River at, analysis of..... 53
Mohican River, Ohio, pollution of..... 141
Monongahela Basin, general features of.. 124-125
map of..... 125
population of..... 126
Monongahela River, water from, analyses of..... 127-128
Monoosoc Brook, Mass., water from, analysis of..... 51
Monroe, Mass., water from Deerfield River at, analysis of..... 77
Monson, Mass., water from, analysis of.. 85
Morse reservoir, Mass., water from, analysis of..... 37
Mount Vernon, Ohio, water from Owl Creek near, analyses of..... 141
Muskingum Basin, Ohio, map of..... 137
pollution in..... 147-153
topography and population of..... 136
Muskingum River, Ohio, water from, analysis of..... 148, 150, 152, 153
Musquapog Lake, Mass., water from, analyses of..... 81
Nagog Pond, Mass., water from, analysis of..... 37
Nashua, N. H., water from Merrimac River at, analysis of..... 55
Nashua River, map of basin of..... 46
pollution of..... 46-54
water from, analyses of..... 53, 54
Natural waters, impurities in..... 16-22
pollution of..... 31-33
New Britain, Conn., water from Pipers Brook near, analyses of..... 92
New Lenox, Mass., water from Housatonic River near, analyses of.. 103
New Milford, Conn., pollution from, decision of court on..... 110-112
New Philadelphia, Ohio, water from Tuscarawas River near, analysis of 145
Newark, Ohio, water from Licking Creek near, analyses of..... 150
Newell, F. H., letter of transmittal by... 11
Newington, Conn., water from Pipers Brook at, analyses of..... 92
Niles, Ohio, water from Mahoning River near, analyses of..... 134
Nimishillen Creek, Ohio, water from, analyses of..... 144
Nitrates, occurrence of..... 26
Nitrites, occurrence of..... 25
Nitrogen, determination of..... 24
Normal water, analyses of..... 29
analysis of, from Massachusetts.. 23, 25, 118
from Miami Basin..... 177-178
from Ohio Basin..... 118
North Andover, Mass., water from Shawsheen River at, analysis of.... 39

Page.

North Branch of Nashua River, Mass., pollution of..... 50-53
water from, analyses of..... 50, 51, 52
North Brookfield, water from, analysis of 88
North Canaan, Conn., water from, analysis of..... 100
North Manchester, Conn., water from Hockanum River at, analyses of..... 91
Northampton, Mass., water from Connecticut River at, analyses of. 95
Northfield Farms, Mass., water from Connecticut River at, analyses of..... 95
Nulhegan River, N. H., power utilized on 71
Odor, determination of..... 28
Oil City, Pa., rainfall at..... 164
Ohio River, character of water of..... 162-170, 173-185
Ohio River Basin, character of..... 116-118
normal water from, analysis of..... 118
rainfall in..... 164
Olentangy Park, Ohio, water from Olentangy River near, analyses of. 139
Olentangy River, Ohio, pollution of and analyses of water from..... 158-162
Ompomponoosuc River, Vt., power utilized on..... 71
Oneota, Lake, Mass., water from, analysis of..... 109
Orange, Mass., water from, analysis of.. 74
water from Millers River near, analyses of..... 76
Organic matter, occurrence of, in surface waters..... 17-19
Ottaquechee River, Vt., power utilized on 71
Owl Creek, Ohio, water from, analyses of. 141
Palmer, Mass., water from Quaboag River near, analysis of..... 84
Park River, Conn., pollution of..... 91-94
water from, analyses of..... 92
Parkersburg, W. Va., rainfall at..... 164
Parks, essential qualities of water in..... 15
Passumsic River, Vt., power utilized on. 71
Pemigewasset River, N. H., power utilized on..... 35
water from, analysis of..... 55
Penacook Lake, N. H., water from, analysis of..... 57
Pepperell, Mass., ground water from, analysis of..... 38
water from Nashua River at, analysis of..... 53
Pipers Brook, Conn., pollution of..... 92
water from, analyses of..... 92
Piqua, Ohio, water from Miami River near, analyses of..... 180
Piscataquog River, N. H., power utilized on 35
Pittsburg, Pa., rainfall at..... 164
typhoid fever epidemic at..... 122
water from Monongahela River at, analysis of..... 127-128
Pittsfield, Mass., water from, analysis of. 100
water from Housatonic River at and near, analyses of..... 101, 102

Page.

ısant, W. Va., rainfall at 164
vater, analyses of 29
ds of, from Massachusetts 25
of natural water, discussion of. 31–33
: Lake, Mass., water from, analysis of 100
n of towns contributing pollut-ing substances to Delaware River 114
ns in Allegheny Basin 121
Blackstone Basin 60–61
Monongahela Basin 126
th, Ohio, rainfall at 164
sential qualities of water used for 14
rrimac River Basin 33–35
River, Mass., power utilized on. 35
Basin, Mass., unpolluted waters in, analyses of 83
from, analysis of 84
of water for various uses 13–16
et River, Mass., water from, analyses of 48
t Akron, Ohio 131
o Valley 164
r, impurities in 16
o, Mass., water from Deerfield River near, analysis of 77
rights, discussion of 32
ter, analyses of. *See* names of streams.
rk, Ohio, water from, analyses of 140
ll, Conn., water from Connecti-cut River at, analyses of 97
lass., water from, analysis of .. 87
iver, Conn., utilized power on .. 71
on, Mass., ground water from, analysis of 38
, Ohio, water from Scioto River at, analyses of 158
eek, Ohio, pollution of 144
nd, Mass., water from, analysis of 37
analyses, discussion of 22–33
e, Mass., water from Sudbury River, near, analysis of 43
iver, Conn., power utilized on .. 71
sin, Ohio, character and area of . 153–154
al water in 154–155
ion in 155–162
ver, water from, analyses of 155, 156, 157, 158, 161
eservoir, Mass., water from, analysis of 37
, W. T., cited on typhoid fever epidemic at Lowell 56
nce to 122
n River, Mass., power utilized on 35
from, analyses of 99
supply from 38–39
Mass., water from Housatonic River at, analysis of 104
e Falls, water from Deerfield River near, *analysis of* 77

Page.

Shelby, Ohio, water from Black Fork, near, analyses of 138, 139
Shenipsit Lake, Conn., water from, analyses of 89
Sidney, Ohio, water from Miami River near, analyses of 180
Soucook River, N. H., power utilized on. 35
Souhegan River, N. H., power utilized on. 35
South Branch of Nashua River, Mass., pollution of 48–49
water from, analyses of 49
South Charleston, Ohio, water from Little Miami River near, analyses of. 172
Spencer, Mass., water from, analysis of .. 83
Spickett River, Mass., power utilized on. 35
Springfield, Mass., water from Connecti-cut River near, analyses of 98
Springfield, Ohio, water from Buck Creek near, analyses of 177, 179
Sterling, Mass., water from Stillwater River at, analyses of 48
Stillwater Creek, Ohio, pollution of and analyses of water from 146–147
Stillwater River, Mass., water from, analyses of 48
Stillwater River, Ohio, pollution and analyses of water from 180–181
Stockbridge, Mass., water from Housa-tonic River at, analyses of 104
water from Lake Averic, analysis of. 100
Stony Brook, Mass., power utilized on ... 35
Storage in Merrimac River Basin 33
Sudbury reservoir, Mass., water from, analysis of 37
Sudbury River, Mass., flow of 36
map of basin of 41
pollution in basin of 40–44
water from, analyses of 43
Sugar River, N. H., power utilized on 71
Suncook River, N. H., power utilized on. 35
Surface waters, impurities in 17–21
Swift River, Mass., water from, analyses of 83
Tatnuck Brook reservoir, Mass., water from, analyses of 62
Tippecanoe City, Ohio, pollution near 180
Trenton, N. J., turbidity of Delaware River at 116
water from Delaware River at, analy-ses of 115
Troy, Ohio, pollution near 180
water from Miami River near, anal-yses of 180
Turbidity, degrees of 23
of Delaware River at Trenton 116
of Ohio River 163
Turners Falls, Mass., water from Connec-ticut River at, analyses of 95
Tuscarawas River, Ohio, pollution in basin of 142–147
water from, analyses of 143, 145, 148
Uhrichsville, Ohio, water from Stillwater Creek near, analyses of 147
Underground waters, impurities in 21–22
Urbana, Ohio, pollution at 178
water from Mad River near, analyses of 177, 178

Page.
Uxbridge, water from Blackstone River at, analyses of 66
Valley Falls, R. I., water from Blackstone River at, analyses of 68
Waits River, Vt., power utilized on..... 71
Walhonding Creek, Ohio, pollution of.. 136-142
water from, analysis of 148
Ware River, Mass., water from, analyses of..... 80, 82
Warehouse Point, Conn., water from Connecticut River at, analyses of. 97
Warren, Ohio, water from Mahoning River near, analyses of..... 133
Water, essential qualities of, for various uses 13-16
Water, drinking, essential qualities of... 15-16
Water, natural, impurities in..... 16-22
pollution of 31-33
Water, normal, analyses of 29
analyses of, from Massachusetts.. 23, 25, 118
from Miami Basin 177-178
from Ohio Basin..... 118
Water, polluted, analyses of..... 29
analyses of, from Massachusetts 25
Water, rain, impurities in 16
Water, surface, impurities in..... 17-21
Water, underground, impurities in 21-22
Waterbury, Conn., pollution from, decision of court on..... 108-110
Wayland, Mass., water from Sudbury River near, analysis of 43
Wells River, Vt., power utilized on 71
West River, Vt., power utilized on..... 71
Westfield, Mass., water from Westfield River near, analyses of 88

Page
Westfield River, map of basin of .....
pollution of 8
power utilized on.....
water from, analyses of..... 87
White River, Vt., power utilized on .....
Williams River, Vt., power utilized on ..
Wills Creek, Ohio, polution of and analyses of water from 148-1
Wilmington, Mass., water from Shawsheen River at, analysis of ....
Winchendon, Mass., water from, analysis of.....
Windermere, Conn., water from Hockanum River at, analyses of.....
Winnepesaukee, Lake, N. H., water from, analysis of .....
Winnepesaukee River, N. H., power utilized on .....
Wooster, Ohio, water from Apple and Killbuck creeks near, analyses of.....
Worcester, Mass., sewage disposal at ....
water from Blackstone River near, analyses of..... 6
Wyandot Grove, Ohio, water from Scioto River at, analyses of .....
Xenia, Ohio, water from Little Miami River near, analyses of 173,
Youghiogheny River, water from, analysis of .....
Youngstown, Ohio, water from Mahoning River near, analyses of .....
Zanesville, Ohio, pollution at .....
water from Licking Creek and Muskingum River near, analyses of

O

er-Supply and Irrigation Paper No. 80 Series M, General Hydrographic Investigations, 4

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE

ELATION OF RAINFALL TO RUN-OFF

BY

GEORGE W. RAFTER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

CONTENTS.

	Page.
on.	9
	10
of rainfall	10
irement of rainfall	11
mination of minimum rainfall	12
nfall increasing?	13
ion of rainfall to altitude	13
of average rainfall in New York State	16
ion of rainfall and run-off into storage, growing, and replenishing iods	16
th of time required to make good a series of rainfall records	17
	19
aws of stream flow	19
of measurement	20
num flow of streams	20
acteristics of the minimum run-off	21
ion of streams into classes	22
nation of run-off from rainfall diagrams	22
ge in lakes	23
putation of annual run-off	24
epancies in computation of run-off	24
al gagings preferable to general studies	24
ulas for run-off	25
mum discharge formula	26
icient table for representative areas	26
y's formulas	27
er of using averages	28
er of using percentages	28
t of low ground water	30
neule's formulas	30
ell's formulas	33
tion between catchment area and maximum and minimum run-off	33
extreme low-water period	35
ation in weir measurements	37
see and Hudson gagings reduced to sharp-crested weir measurents	37
ion	38
gerald's formula for evaporation	38
oration relations	39
t of wind and other meteorological elements	39
istency of rate of evaporation	40
ative evaporation	40

P

Ground water
Movements of ground water
Growth of streams by accession of ground water
Relation of geologic structure to run-off
Effects of forests
Do forests increase rainfall?
Effect of forests on run-off
Why the removal of forests affects stream flow
Forestation of the Croton catchment area
Details concerning tables and diagrams
Topographic relations of catchment areas of streams tabulated
Classification of streams
Description of Tables 1–12
Description of precipitation and evaporation diagrams
Exponential formula
Description of run-off diagrams
Summary
Tables
Index

TABLES.

		Page.
1.	**Muskingum River**, 1888–1895, inclusive	85
2.	**Genesee River**, 1890–1898, inclusive	85
3.	**Croton River**, 1868–1899, inclusive	86
4.	**Lake Cochituate**, 1863–1900, inclusive	88
5.	**Sudbury River**, 1875–1900, inclusive	90
6.	**Mystic Lake**, 1878–1895, inclusive	92
7.	**Neshaminy Creek**, 1884–1899, inclusive	93
8.	**Perkiomen Creek**, 1884–1899, inclusive	94
9.	**Tohickon Creek**, 1884–1898, inclusive	95
10.	**Hudson River**, 1888–1901, inclusive	96
11.	**Pequannock River**, 1891–1899, inclusive	97
12.	**Connecticut River**, 1872–1885, inclusive	
13.	**Mean or average rainfall**, run-off, and evaporation for storage, growing, and replenishing periods for 12 streams of the United States	98 99
14.	**Low-water periods on Muskingum River**	100
15.	**Low-water periods on Genesee River**	102

ILLUSTRATIONS.

		Page.
FIG. 1.	Diagram showing relation between precipitation, evaporation, run-off, and temperature on the Upper Hudson River	63
2.	Diagram showing the relation between evaporation and temperature on the Upper Hudson River, the years being arranged according to the amount of evaporation	64
3.	Diagram showing the relation between precipitation, run-off, evaporation, and temperature on the Upper Genesee River, the years being arranged in order of dryness	64
4.	Diagram showing the relation between precipitation, evaporation, run-off, and temperature on the Sudbury River, Massachusetts	65
5.	Diagram showing relation between precipitation, evaporation, run-off, and temperature on the Sudbury River, Massachusetts, the years being arranged in order of dryness	66
6.	Diagram showing the relation between evaporation and temperature on the Sudbury River, the years being arranged according to the amount of evaporation	67
7.	Diagram showing the relation between the precipitation, run-off, evaporation, and temperature on the Muskingum River, Ohio, the years being arranged in order of dryness	67
8.	Diagram showing the relation between the precipitation, evaporation, run-off, and temperature in the Lake Cochituate Basin, the years being arranged in order of dryness	68
9.	Diagram showing the relation between evaporation and temperature in the Lake Cochituate Basin, the years being arranged according to the amount of evaporation	69
10.	Diagram showing the relation between the precipitation and run-off in inches on the Upper Hudson River	70
11.	Diagram showing the relation between the precipitation and run-off in inches on the Upper Hudson River, expressed by exponential formula	71
12.	Run-off diagram of Hudson and Genesee rivers	72
13.	Run-off diagram of Muskingum River	73
14.	Run-off diagram of Passaic River	74
15.	Run-off diagram of Sudbury River	75
16.	Run-off diagram of Croton River	76
17.	Diagram showing the relation between precipitation and run-off in the Upper Hudson River Basin during the storage period	77
18.	Diagram showing the relation between the precipitation and run-off in the Upper Hudson River Basin during the growing period	77
19.	Diagram showing the precipitation and run-off in the Upper Hudson River Basin during the replenishing period	78
20.	Diagram showing the relation between precipitation and run-off in the Sudbury River Basin during the storage period	78
21.	Diagram showing the relation between precipitation and run-off in the Sudbury River Basin during the growing period	79
22.	Diagram showing the relation between precipitation and run-off in the Sudbury River Basin during the replenishing period	79
23.	Section of Mechanicville dam	80

THE RELATION OF RAINFALL TO RUN-OFF.

By GEORGE W. RAFTER.

INTRODUCTION.

The run-off of a stream is influenced by many complex conditions—as, for instance, amount of rainfall and its intensity, nature of soil, slope of surface, and area and configuration of catchment basin. It is also influenced by geologic structure, forests, wind, force of vapor pressure, and other elements. Data are still lacking for a really satisfactory discussion of the question, although they have accumulated so rapidly during the last few years that many conservative conclusions can be drawn which may be accepted as substantially true.

The subject has been discussed in the Transactions of the American Society of Civil Engineers by Messrs. Herschel, Fteley, FitzGerald, Babb, and others in a series of able papers,[a] but no one of these exhibits a complete view.

It has also been discussed in other publications, but so far as known to the writer the Transactions of the American Society contain the most complete discussion of the subject that can be found in English engineering literature.

As a result of many years' study of the problem indicated by the title of this paper the writer has come to the conclusion that no general formula is likely to be found expressing accurately the relation of rainfall to the run-off of streams, for streams vary widely in their behavior, and when they do agree the agreement is usually accidental. As a general proposition we may say that every stream is a law unto itself.

The final formula of run-off for a given stream, therefore, will differ in some particulars from that for every other, except that there may be accidental resemblances as regards slope, shape of catchment area, or some other peculiarity. It is, however, true that an empirical formula may be made for certain classes of streams which will give approximately the run-off for a series of years.

[a] See Trans., Vol. X, p. 225; Vol. XXVII, p. 253; and Vol. XXVIII, p. 323.

ries of rainfall given in books of twenty or thirty years ago
now wholly accepted. Still there is one simple principle upo
no disagreement exists—that in order to produce rain the t
ture of the air must be suddenly cooled below the dew point.
the air is thus cooled a portion of the vapor is changed to th
state and the particles thus formed may float away with the
they may increase in size and fall to the ground by virtue of
Whether the condensation results simply in cloud, or whet
falls, depends on the magnitude of the temperature change
place in the air mass.

The precise manner in which air is cooled to produce rain,
by contact or by mixing, is not clearly apprehended. Coo
expansion, as air ascends, is one of the most effective causes
fall. The ascensional movement is brought about in severa
probably the most important of which is circulation of air in
storms, by a radial inflow from all sides and an ascensiona
ment in the center. A very large percentage of the rain of the
States is precipitated in connection with the passage of storm
class.[c]

Mr. Henry discusses the precipitation of the United State
the following topics: (1) The statistics used and their accur
Geographic distribution and annual allowance; (3) Monthly d
tion by districts and types; (4) The precipitation of the crop-
season; (5) Secular variations; (6) Details of the precipita
geographic districts; and (7) Excessive precipitation.

The chapter on "Excessive precipitation" is probably, from
meeting point of view, the most important. Mr. Henry states

s at the Weather Bureau stations equipped with self-registering es, compiled from all available records. Inasmuch as this paper y be readily referred to in the publication cited, further detail is itted.

MEASUREMENT OF RAINFALL.

The subject, "How close may rainfall be measured?" has been fully cussed by Prof. Cleveland Abbe.[a] Professor Abbe states that the luence of altitude was first brought to the attention of the learned rld by Heberden who, in 1769, in a memoir in the Transactions the Royal Society of London, stated that a gage on Westminster bey, over 150 feet above the ground, caught less than half as ch as a gage at the ground.

Profs. Alexander D. Bache and Joseph Henry, and Mr. Desmond tzGerald have studied the question extensively in this country. . FitzGerald's results may be found in the Journal of the Associan of Engineering Societies for August, 1884.[b]

Mr. FitzGerald kept two gages, one at a height of 2 feet 6 inches ove the level of the ground, and the second at a distance of 150 et from the first, and at an elevation of 20 feet 4 inches above the wer gage. Both gages were 14.85 inches in diameter. These gages re located at Chestnut Hill reservoir, in the city of Boston, but the servations for wind velocity were taken from the Signal Service servations, 5 miles distant. With only five exceptions during the e-year period, the upper gage delivered materially less water than e ground gage, the average difference being 10.6 per cent for the ole period. But snowfalls and mixtures of snow and rain are not cluded in the table of data given in the paper.

The results recorded by Professor Abbe are somewhat more extenve than those presented by Mr. FitzGerald, though Mr. FitzGerald ates in his paper that he has prepared a series of experiments with ne gages and a self-recording anemometer, from which in the course time some more definite results may be reached. So far as the riter knows, this second series of observations has not been pubished.

In order to show how the catch of rainfall diminishes with height of e gage, Professor Abbe gives in his Table No. IV the results of obsertions at different places. These range from 90 per cent of a gage the ground to 47 per cent. In Tables Nos. I, II, and III, Professor bbe also gives the result of various gages, which gave 52 to 7 per cent ss of rainfall, and from 80 to 16 per cent less of snowfall, than gages the ground. Professor Abbe remarks that these tables show conusively the large influence of wind on the catch of rain, but show

[a] Determination of the true amount of precipitation and its bearing on theories of forest influences, by Cleveland Abbe: Appendix I of Bulletin No. 7, Forest Influences; Forestry Division, United States Department of Agriculture.

[b] Does the wind cause the diminished amount of rain collected in elevated rain gages? By mond FitzGerald: Jour. Assoc. Engineering Societies, Vol. III, No. 10 (August, 1884).

nothing of its influence on the catch of snow. As an observational method of obtaining the true rainfall from gage readings, Professor Abbe suggests the following as offering a fair approximation:

If the present gage has been standing in an open field at a few feet elevation, place two or more similar gages near it, and similarly located as far as obstacles are concerned, except only that one of these is to be decidedly lower than the old one and the other decidedly higher. From a comparison of the simultaneous records of any two gages and their altitudes, we should for each separate rainfall, rather than for the monthly and annual sums, deduce the normal rainfall by the solution of two or more equations of the form:

Observe catch of gage = (1 − x altitude) × (desired catch of normal pit gage). (1)

Where x is the unknown special coefficient of deficiency due to wind at the altitude—that is to say, having two gage catches, c_1 and c_2 for the two altitudes H_1 and H_2—we obtain the true rainfall (R) by the formulas:

$$c_1 = (1 - x\sqrt{H_1})\ R; \text{ and} \tag{2}$$

$$c_2 = (1 - x\sqrt{H_2})\ R. \tag{3}$$

whence,

$$R = \frac{c_1\sqrt{H_2} - c_2\sqrt{H_1}}{\sqrt{H_2} - \sqrt{H_1}} = c_1 + \frac{1}{\sqrt{\frac{H_2}{H_1}} - 1}(c_1 - c_2) = c_1 + n(c_1 - c_2). \tag{4}$$

If c_1 and H_1 relate to the lower gage, we shall generally have $c_1 > c_2$ and $H_1 < H_2$, and the coefficient n will be a positive fraction, for value of which, for such combinations as may easily occur in practice, a table is given in the paper.

It is evident then, without special discussion, that nearly all rainfall measurements thus far made in the United States are only approximations, and that while they remain in this state to carry them out to more than one decimal place is an unnecessary refinement.

DETERMINATION OF MINIMUM RAINFALL.

The writer has spent considerable time in an attempt to determine about what the minimum rainfall at any particular station may be expected to be; or, rather, he has endeavored to ascertain the relation between the minimum rainfall and the maximum. In the course of this quest he has examined practically all the records in the State of New York, as well as many records in New Jersey, Pennsylvania, Michigan, Illinois, Nebraska, Colorado, and Wyoming, as well as in Canada. As a general rule, to which there are some exceptions, the minimum rainfall may be placed at about one-half of the maximum. That is, if the maximum rainfall at a given station is about 50 inches, the minimum will be in the vicinity of 20 to 25 inches. In some cases the minimum will be not more than one-third of the maximum, or even somewhat less than one-third; occasionally, not more than one-quarter. It is not intended, however, to lay this down as an absolutely universal rule, but rather, for the present, as a somewhat imperfect guide. As a further rough guide it remains to point out that in case a given record does not conform substantially to the foregoing it may be assumed that either the minimum or the maximum,

s the case may be, is still to occur. Near the seacoast, where the pply of moisture in the air is more nearly constant, there is less riation than in the interior, and the rule that the maximum is nible the minimum is more generally true. This proposition is also nerally true as regards English meteorology.

IS RAINFALL INCREASING?

This question has been discussed by Prof. Mark W. Harrington,[a] o, however, reached no very definite conclusion, although he is posed to answer it in the negative. The method of discussion fol-ved was to reduce the annual rainfalls to a series of means of ch five years. These means were entered on a succession of maps, e years apart in time, and on these maps was drawn the line of 40 hes of annual rainfall. The question to be determined is, as we aw this line for each five-year mean, Does it change its position in y regular and systematic way?

An examination of the detail shows that while these lines are sub-ct to limited fluctuations there are no uniform or systematic fluctu-ions. The line of equal rainfall for 1861–1865 occupied nearly the me position as the line for 1886–1890. The variations are some-nes extensive, but without systematic progress. Professor Har-ngton therefore concludes that with the data at hand there is not fficient evidence of systematic fluctuation of the rainfall.

RELATION OF RAINFALL TO ALTITUDE.

This matter has been referred to in a discussion of Mr. Noble's per on Gagings of Cedar River, Washington,[b] where the statement s been made that in the State of New York the rainfall records ow both increase and diminution of precipitation with increase of titude. The Hudson River catchment area shows a higher precipi-tion at the mouth of the river than it does at its source in the dirondack Mountains, while the Genesee River shows the opposite, mely, higher precipitation at its source than at its mouth.

According to a table of average monthly, annual, and seasonal pre-pitation in Mr. Turner's monograph on the climate of New York ate[c] it appears that the coast region, which includes Block Island, st Hampton, Setauket, Fort Columbus, New York City, Mount easant, Tarrytown, White Plains, Croton dam, and North Salem, s an average annual precipitation of 44.93 inches. With the excep-n of Block Island these stations are all in New York and not far

---

[a] Rainfall and snow of the United States, compiled to the end of 1891, with annual, seasonal, nthly, and other charts, by Mark W. Harrington: Bulletin C, Weather Bureau, U. S. Dept. of riculture.

[b] Trans. Am. Soc. Civil Eng., Vol. XLI, pp. 1-26.

[c] The climate of New York State, by E. T. Turner, C. E., late meteorologist of the New York ther bureau: Fifth Ann. Rept. New York Weather Bureau, 1893. Reprinted in Eighth Ann. pt. of the bureau, 1896.

from the coast, and they range in elevation above tide water from 1 feet at East Hampton to 361 feet at North Salem. The average el vation of the coast region is 132 feet. The records vary in lengt from 7 years to 49 years, with a total of 195 years. Five of the st tions are in Westchester County.

As given by Mr. Turner, the northern plateau includes Constabl ville, Lowville, Fairfield, Johnstown, Pottersville, Elizabethtown Keene Valley, and Dannemora, in the counties of Lewis, Herkime Warren, Essex, and Clinton. According to the table the averag annual precipitation at these places is 38.97 inches. The elevation the stations above tide ranges from 600 feet at Elizabethtown to 1,3 feet at Dannemora, with an average elevation of 973 feet. The record vary in length from 4 to 22 years, with a total of 73 years.

Again, the western plateau, which includes stations in Cattaraugu Wyoming, Allegany, Steuben, Livingston, and Chemung counties, ha an average elevation above tide of 1,307 feet, ranging from 1,950 fe to 525 feet, and has an average annual precipitation of 35.58 inche while the Hudson Valley, which includes stations in Putnam, Orange Dutchess, Ulster, Columbia, Albany, Rensselaer, and Washingto counties, has an average elevation of 230 feet above tide, with a average annual precipitation of 38.46 inches. The records range fro 9 years to 65 years, with a total of 277 years.

The Great Lakes region, with an average elevation of 494 feet, has a average annual precipitation of 35.17 inches, while the central lak region, with an average elevation of 690 feet, has an average annua precipitation of 43.41 inches.

Mr. Turner's table is based on a calendar year, from January t December, inclusive. Further data may be obtained from this exce lent table.

In Table No. 24 of the Upper Hudson Storage Surveys Report fo 1896 there is given the mean precipitation of the Upper Hudson catch ment area. The stations therein included are: Albany, 1825–1895, 7 years; Glens Falls, 1879–1895, 17 years; Keene Valley, 1879–1895, 1 years; western Massachusetts, 1887–1895, 9 years; northern platea 1889–1895, 6½ years; Lowville Academy, 1827–1848, 22 years; John town Academy, 1828–1845, 18 years; Cambridge Academy, 1827–183 13 years; Fairfield Academy, 1828–1849, 22 years; Granville Aca emy, 1835–1849, 15 years. Assuming the northern plateau as a un the total number of years is 199½, and the mean of all is 37.4 inche A reference to the rainfall map in the report of the United Stat Board of Engineers on Deep Waterways will show that this is nece sarily an approximation, because of great lack of stations in t interior of this region.

As regards the catchment area of the Upper Genesee River, the is a very decided increase in rainfall as one goes toward the sourc For the years 1889–1896, inclusive, the rainfall in the upper area *this stream* was 42.19 inches, while at Rochester for the same yea

it was 35.64 inches. This statement is especially interesting, because there seems to be a well-marked line dividing the smaller rainfalls of the lower area from the higher rainfalls of the upper. At Hemlock Lake, Avon, and Mount Morris the rainfalls are all low, the average at Hemlock Lake from 1876–1895, inclusive, being 27.56 inches. In 1880 it was 21.99 inches; in 1879, 22.16 inches, and in 1881 only 24.36 inches. We have here three years of exceedingly low rainfall, in which the run-off must have also been very low. In 1895 the rainfall at Hemlock Lake was only 18.58 inches. The average precipitation at Avon and Mount Morris from 1891 to 1896, inclusive, was 30.12 inches. In 1895 it was only 25.05 inches. The following are stations at which it was much higher for the years 1891 to 1895, inclusive: Leroy, 45.25 inches, and Arcade, 41.60 inches.

The statements of precipitation in Genesee River catchment area are all based on a water year, December to November, inclusive.

The following are from Russell's Meteorology,[a] illustrating Atlantic coast rainfalls, and are the averages derived from observations extending from 1870 to 1888. The rainfalls are stated to be fairly representative for large districts of country around the places.

At Jacksonville the weather bureau office is at an elevation above tide of 43 feet, while the average annual rainfall is 57.1 inches. At Norfolk the elevation of weather bureau is 57 feet above tide, and the average rainfall is 51.7 inches. At Boston the weather bureau office is 125 feet above tide, and the average rainfall is 46.8 inches.

The following illustrate the change as one goes north through the Mississippi Valley: At New Orleans the weather bureau office is 54 feet above tide, the average rainfall 62.6 inches; at St. Louis, weather bureau office 567 feet above tide, average rainfall 37.8 inches; at St. Paul, weather bureau office 850 feet above tide, average rainfall 28.9 inches.

The following illustrate the Rocky Mountain region: At Fort Grant, Ariz., elevation of weather bureau 4,833 feet, average rainfall 15.8 inches; at Denver, elevation of weather bureau 5,300 feet, average rainfall 14.7 inches; at Fort Benton, Mont., elevation 2,565 feet, average rainfall 13.2 inches.

The following illustrate the Pacific coast region: At Portland, elevation of weather bureau office is 157 feet, average rainfall 50.3 inches; San Francisco, elevation 153 feet, average rainfall 23 inches; San Diego, elevation 69 feet, average rainfall 10.2 inches.

These figures abundantly support the proposition that in the United States the rule of increased precipitation with higher altitude is by no means universal. The writer can not say positively, because he has not examined the vast number of records with reference to this point, but he thinks it quite possible that the reverse is more nearly true. That is, owing to distance from the ocean, prevailing direction

[a] Meteorology, by Thomas Russell, U. S. Asst. Engineer.

of wind, and other causes, it is probable that for the entire country precipitation decreases with higher altitude rather than increases.

The decision of this question will depend to some extent upon the steepness of ascent. Thus on Mount Washington, which is projected into the air far above the surrounding mountains, the rainfall is about 83 inches. In other cases, where the ascent is gradual, no increase is apparent. The same is also frequently true of sharp ascents. On Longs Peak, in Colorado (elevation 14,271 feet), the rainfall in 1899 was 16.7 inches.

Morever, the writer has mostly avoided comparatively small differences in rainfall—those not exceeding 2 to 2.5 inches. In such cases the difference is too small to be any certain guide. Especially is this true in the case of the northern plateau, where there is still a great lack of stations. The differences between high altitudes and low should be as much as 5 or 6 inches. Again, whether the excess rainfall occcurs in the winter or summer months must be taken into account. If it occurs in the summer, even 3 inches of rainfall may not make more than 0.1 or 0.2 inch in the stream. Rainfall and run-off observations are not yet, nor are they likely to ever be, definite enough to take into account an annual difference of much less than about 1 to 1.5 inches. Again, the writer has ceased to be excessively particular about the total of the annual rainfall. Assuming some considerable length of record, small errors have relatively slight effect. This matter is referred to here because nearly all rainfall records—at any rate in the United States—have more or less error in them, and while it is desirable to have records as reliable as possible, a few errors do not affect a record very seriously. It is nevertheless very desirable to know the history of the record in order to insure the degree of confidence to be placed in it.

MAP OF AVERAGE RAINFALL IN THE STATE OF NEW YORK.

On Pl. XCVIII of the Report to the United States Board of Engineers on Deep Waterways, the writer has given the average rainfall at a large number of stations throughout the State of New York. When this map was prepared considerable time was expended in drawing lines of equal rainfall upon it, but so many discrepancies appeared that it was finally concluded, for the present, that it should be allowed to stand without such lines. The only way these contours could be drawn with any satisfaction was to omit stations which conflicted too much therewith. This, the writer did not feel justified in doing. The observations are not extensive enough to enable one to draw these lines.

DIVISION OF RAINFALL AND RUN-OFF INTO STORAGE, GROWING, AND REPLENISHING PERIODS.

The writer has found it very convenient to divide rainfall and run-*off records* into the three periods, those of storage, growing, and

plenishing, with a water year beginning December 1 and ending vember 30. The storage period includes the months from Decem- to May, inclusive, during which the evaporation and absorption plants are relatively slight, and a very large proportion of the nfall appears in the streams.

The growing period, June to August, inclusive, includes the riod of active vegetation, when evaporation and absorption by nts are most notable. During this period, frequently not more an 0.1 of the rainfall appears in the streams, and sometimes not re than 0.05 or even less. Ground water tends to become lower d lower during this period, unless the rainfall is much higher than e average.

In the replenishing period, September to November, inclusive, with e normal rainfall, ground water tends to recover, and the run-off is ger than in the preceding period. This period is replenishing in is, that there is a tendency to return to normal conditions.

No hard and fast rule, however, can be laid down as to the begin- ng and ending of these periods. In some years the beginning of the ter year should be placed at November 1, instead of December 1, ile in others the storage period may end with April. Very often, e period runs into another, but after considerable study the fore- ing divisions have been accepted as, on the whole, best represent- g all the conditions. In England many hydrologists begin the water ar with September 1 as best suiting the conditions. The same thing s been done by the Philadelphia water department in tabulating the ta of Neshaminy, Perkiomen, Tohickon, and Wissahickon creeks d Schuylkill River.

One great advantage of dividing records into these periods is as llows: Since evaporation and plant absorption are light during the onths of the storage period, it follows to a great degree that the nount of water which can be stored is exhibited by the rainfall of e storage months. Realizing this fact, it has been the writer's habit r several years, in storage projects, to first tabulate rainfall in the anner indicated. Such procedure has the advantage that it leads e away from the contemplation of mere detail. There is a positive advantage in considering the monthly quantities, for which there no compensation. The division into the three periods exhibits the re important characteristics without overburdening the mind. It believed that a considerable advance on ordinary practice has been de by proceeding in the manner stated.

NGTH OF TIME REQUIRED TO MAKE GOOD A SERIES OF RAINFALL RECORDS.

This question is partially answered in the writer's second report the Upper Hudson Storage Surveys, for 1896, by a short analysis

of a paper by Alexander R. Binnie, member of the Institution of Civil Engineers.[a]

One of the important problems worked out by Mr. Binnie is an answer to this question: What is the least number of years of which the continuous record, when the average rainfall has been determined, will not be materially affected, so far as the value of the mean is concerned, even if the record be extended by a greater number of years' observations? Also, What is the probable accuracy of any record the length of which is less than that necessary to give an average which will not be materially altered when the record is extended?

Space will not be taken to show Mr. Binnie's views in detail, for which reference may be made to the abstract in the second Hudson report, or, for the complete views, to the paper in the Proceedings of the Institution of Civil Engineers, but assuming that the observations are properly made it is stated that "dependence can be placed on any good record of thirty-five years' duration to give a mean rainfall correct within 2 per cent of the truth."

Further, it can be stated that for records from twenty years to thirty-five years in length, the error may be expected to vary from 3.25 per cent down to 2 per cent, and that for the shorter periods of five, ten, and fifteen years, the probable extreme deviation from the mean would be 15 per cent, 8.25 per cent, and 4.75 per cent, respectively.

A twenty years' record, therefore, may be expected to show an error of 3.24 per cent. This is about as close as rainfall records in this country can be expected to agree, as comparatively few are much beyond twenty years in length.

In his paper on the Rainfall of the United States, Mr. Henry has examined this question, using long records at New Bedford, St. Louis, Philadelphia, Cincinnati, and other places. The rainfall has been measured at New Bedford for 83 consecutive years, and at St. Louis for 60 years. For a 10-year period Mr. Henry found the following variations from the normal: At New Bedford + 16 per cent and − 11 per cent; at Cincinnati, + 20 per cent and − 17 per cent; at St. Louis, + 17 per cent and − 13 per cent; at Fort Leavenworth, + 16 per cent and − 18 per cent; and at San Francisco, + 9 per cent and − 10 per cent. For a 25-year period, it was found that the extreme variation was 10 per cent, both at St. Louis and New Bedford. Mr. Henry reached the conclusion that at least 35 to 40 years' observations are required to obtain a result that will not depart more than ± 5 per cent from the true normal. The average variation of a 35-year period was found to be ± 5 per cent, and for a 40-year period ± 3 per cent.

This preliminary study indicates slightly more range than was found

[a] On mean or average rainfall and the fluctuations to which it is subject, by Alexander R. Binnie, Inst. C. E.: Proc. Inst. C. E., Vol. CIX (1892), pp. 89–172.

y Mr. Binnie, although it may be remembered that the observations f the latter are far more extensive than Mr. Henry's.

Again, since the run-off is a function of the rainfall, it follows that must be affected in some degree in a similar manner. As to just he relation, so far as known, very few computations have been made. ndeed, very few run-off tabulations are extant which are long enough o settle this question. It is clearly, therefore, very difficult to solve efinitely so abstruse a problem as that of the extent to which forests ffect rainfall. All solutions are necessarily, and will be for some me to come, tentative in their character.

RUN-OFF.

THE LAWS OF STREAM FLOW.

A general statement of these laws from Mr. Vermeule is as follows:

The waters of the earth are taken up by the process which we call evaporation d formed into clouds, to be again precipitated to earth in the form of rain or ow. Of the water which falls upon the basin of a stream, a portion is evapo- ted directly by the sun; another large portion is taken up by plant growth and ostly transpired in vapor; still another portion, large in winter but very small summer, finds its way over the surface directly into the stream, forming sur- ce or flood flows; finally, another part sinks into the ground, to replenish the eat reservoir from which plants are fed and stream flows maintained during the riods of slight rainfall, for the rainfall is frequently, for months together, much s than the combined demands of evaporation, plant growth, and stream flow. hese demands are inexorable, and it is the ground storage which is called upon supply them when rain fails to do so.

All of these ways of disposing of the rain which falls upon the earth may be assed as either evaporation or stream flow. Evaporation we make to include rect evaporation from the surface of the earth, or from water surfaces, and also e water taken up by vegetation, most of which is transpired as vapor, but a rtion of which is taken permanently into the organisms of the plants. Stream ow includes the water which passes directly over the surface to the stream, and so that which is temporarily absorbed by the earth to be slowly discharged into e streams. A portion, usually extremely small, passes downward into the earth d appears neither as evaporation nor as stream flow. It is usually too small to considered, and we may for our purposes assume that all of the rain which falls pon a given watershed and does not go off as stream flow is evaporated, using e latter word in the broadened sense which we have above described.

Probably one very important effect of forests is that upon the round-water flow of streams. The stream with a catchment area holly or largely in forests will show, without exception, a much bet- er ground flow than one with the area denuded of forests. Nesham- y and Tohickon creeks may be cited as streams with the smallest mount of forest and the lowest curve of ground-water flow. Pos- ibly this is not entirely due to forests, but it may be assumed that hey bear some relation to the result.[a]

[a] Examples of ground-water curves for the chief streams herein considered may be found in r. Vermeule's report on the flow of streams, etc., in Final Rept. State Geologist of New Jer- y, Vol. III. Trenton, 1894.

UNITS OF MEASUREMENT.

Clemens Herschel, member American Society Civil Engineers, in his paper on Measuring Water,[a] has defined the essential elements of this question in the following terms:

> For most purposes the unit of volume, when using English measures, has been agreed upon in favor of the cubic foot, and the nations of the earth being fortunately agreed upon their measures of time, have settled upon one second of time as the unit to use in measuring water. Nevertheless, the million United States gallons in twenty-four hours has become a standard for city water supply practice in the United States, and an acre in area covered an inch or a foot deep in a month or in a year is used in irrigation practice. But I would warn all engineers to be very slow to add to the number of such standards of measure for flowing water, and to abstain from and frown down such absurd standards as cubic yards per day, or tons weight of water per day, or even cubic feet per minute (instead of second), and other incongruities. * * * As exercises in the art of arithmetic for children such computations may have value, but in the work of civil engineers they become a stumbling block to an advance of knowledge, and while unduly magnifying the unessentials they indicate a deplorable lack of appreciation of the essentials of the art of the civil engineer.
>
> Cubic measures do well enough for the contents of vessels, or as we may express it, for dealing with the science of hydrostatics. But so soon as the water to be measured is in motion, or so soon as the science of hydraulics has been entered upon, we must get clearly in our minds the idea of rates of flow, or of a procession of such cubic volumes passing a given point in a certain unit of time, as of a flow of so many cubic feet per second.

Very little can be added to what Mr. Herschel has here said. It is a clear exposition of the whole subject. Such units as cubic feet per day and cubic miles have clearly no place in a modern paper on hydrology.

The unit of inches on the catchment area may, however, be pointed out as an exception to the foregoing general rule. This unit is exceedingly convenient because it admits of expressing rainfall and run-off in the same unit and without reference to the area. It brings out a number of relations not otherwise easily shown, as will be exhibited in discussing the tables accompanying this paper.

MINIMUM FLOW OF STREAMS.

Very little can be added to our knowledge of the minimum flow of streams beyond what has already been stated in Water Supply and Irrigation Paper No. 24, Water Resources of the State of New York, Part I, which applies particularly to streams in the State of New York. Summarizing the information there given, we may say that for streams issuing from regions of heavy, compact soil, mostly deforested, the extreme minimums are likely to run as low as 0.1 of a cubic foot per square mile per second. They may even in an extreme drought go as low as 0.05 of a cubic foot per square mile per second.

[a] Measuring Water, by Clemens Herschel; An address to the students of Rensselaer Polytechnic Institute, Troy, N. Y.

Oswego River, by reason of large lake pondage, has a minimum flow of about 0.3 of a cubic foot per square mile per second. For a similar reason the Upper Hudson will not usually go less than 0.3 of a cubic foot per square mile per second, although in the summer of 1899 it probably did not exceed 0.2 of a cubic foot per square mile per second. This, however, was unusual. The streams of Long Island, issuing from sand plains, may be expected to give minimum flows of from 0.5 to 0.6 of a cubic foot per square mile per second. The streams of the northern part of New York, issuing from denser forests than the others, also give minimum yields somewhat in excess of 0.3 of a cubic foot per square mile per second. The streams tributary to Mohawk River, on the south side of the valley, will give minimum flows of not more than one-half of what the streams tributary on the north side give. As to the streams of the far West, many of them are frequently dry for several months at a time. A typical stream of this character is the Platte River, with a catchment area at Columbus, Nebr., of 56,867 square miles.[a]

CHARACTERISTICS OF THE MINIMUM RUN-OFF.

Since the rainfall varies so widely, the run-off, which is a function of the rainfall, will also vary widely. On the Hudson River the maximum run-off of 33.08 inches, with a rainfall of 53.87 inches, occurred in 1892. The minimum, with a run-off of 17.46 inches and a rainfall of 36.37 inches, occurred in 1895. On the Genesee River the observed maximum rainfall of 47.79 inches, with a run-off of 19.38 inches, occurred in 1894.[b] The minimum rainfall of 31 inches, with a minimum run-off of 6.67 inches, occurred in 1895. These figures of rainfall indicate that either the extreme maximum or the extreme minimum rainfall has not yet occurred on the catchment area of this stream.

On the Muskingum River the maximum rainfall thus far observed is 56.97 inches, with a maximum run-off of 26.84 inches, which occurred in 1890. The observed minimum rainfall of 29.84 inches, with the corresponding minimum run-off of 4.9 inches, occurred in 1895. It is also doubtful if either the extreme maximum or the extreme minimum rainfall has been yet observed on the catchment area of this stream. As to whether the rainfall will go lower there is no certain way of determining. Moreover, 4.9 inches seems a very low run-off—and the run-off is not likely to be less than this figure. However, the run-off in any year depends very largely on the rainfall of the months from

[a] For an extensive list of streams of which the maximum and minimum flows are given, the following may be consulted:
(1) Water Power of the United States, Tenth Census, Vol. I, pp. XXVIII and XXIX.
(2) Twentieth Ann. Rept. U. S. Geol. Survey, Part IV, Hydrography, pp. 46-63.
(3) Report on water supply, water power, the flow of streams and attendant phenomena, by Cornelius C. Vermeule: Final Report State Geologist of New Jersey, Vol. III.

[b] In the combined Genesee River and Oatka Creek record the maximum run-off of 21.22 inches occurred in 1890, when the rainfall is placed at 47.54 inches. This, however, is less reliable than the rainfall and run-off of 1894, which latter is accordingly given the preference.

December to May, inclusive. There may possibly be, therefore, lower annual run-off than 4.9 inches, even though the total rainfa should exceed 29.84 inches. The rainfall for December to Ma inclusive, was 13.04 inches. The run-off for that period was 4.0 inches.

DIVISION OF STREAMS INTO CLASSES.

The foregoing statements indicate that, as regards run-off, stream of the eastern part of the United States may be divided into classe In the first class will fall streams where the maximum rainfall is fro 50 to 60 inches, with corresponding run-off somewhat more than on half of the rainfall. The minimum run-off will be about one-half th rainfall, or a little less. These statements, it may be again repeate are general ones, to which there are exceptions.

Another class of streams, of which the Genesee and Muskingu rivers are typical, are those with maximum rainfall on their catch ments of 40 to 50 inches and with corresponding run-off somewha less than one-half the rainfall. The minimum run-off for these stream is from one-fourth to one-sixth of the corresponding rainfall, or fro about 16 per cent to 25 per cent.

A further class, the far Western streams, may be mentioned, i which the run-off is only a very small percentage of the rainfall, i some cases not more than 4 per cent to 5 per cent, or at times eve less. Probably comprehensive study would further subdivide thes streams, but the intention at present is to merely call attention t some of the more marked peculiarities as a basis for final detaile study.

If one takes the streams of the far West, as, for instance, Lou River, in Nebraska, with a catchment area of 13,542 square mile where the rainfall in 1894, observed at 24 stations, was, on an averag only 12.84 inches and the run-off of the stream did not much exceed inch, he will find entirely different conditions from those above state In many cases streams in that locality run much less than 1 inc For instance, the South Platte, at Denver, Colo., in 1896, with a rai fall of 11.84 inches, ran 0.62 inch. The catchment area at this plac is 3,840 square miles. At Orchard, Colo., the South Platte, in 189 with a rainfall of about 17 inches, ran 0.9 inch. The catchment are at this place is 12,260 square miles. The Republican River, at Junc tion, Nebr., with a rainfall of about 26 to 28 inches, in 1898, ran 0.3 inch. The catchment here is 25,837 square miles in extent.

The foregoing statements indicate the essential truth of the propo sition already announced that, broadly, each stream is a law unt itself. Any formula, for either maximum, average, or mean run-off which does not take this into account is incomplete.

ESTIMATION OF RUN-OFF FROM RAINFALL DIAGRAMS.

Can run-off of streams be estimated from diagrams of monthly rain fall? The writer has spent considerable time on this problem withou

arriving at any very satisfactory conclusion. For some months such a diagram may be made to fit quite closely, while for others differences of as much as 2 or 3 inches appear. The conclusion of the writer is, therefore, that such diagrams are at the best crude approximations. Such study is, however, very fascinating, and it is not surprising that different hydrologists have attempted at various times its solution. Two lines of work may be mentioned. One is, by a combination of a large number of streams and their rainfall, to attempt to produce a universal formula. This, however, as has been already shown, leads to what is, in effect, a hodgepodge. Averages so applied "bring out class likenesses, to the exclusion of individual features."

The other method is to plat rainfall and run-off appearing monthly in inches, as abscissas and ordinates, respectively, and in this way to preserve the individual peculiarities of each stream. In some respects the most satisfactory way is to plat the rainfall and run-off of the storage, growing, and replenishing periods, thus grouping similar characteristics.

STORAGE IN LAKES.

The run-off of a stream is very materially influenced by the number of lakes within its catchment area. If there are many, flood flows may be expected to be very much smaller than they otherwise would be. The temporary pondage in the lakes is the cause of this. The Oswego River is a stream of this character. This stream has a total catchment area of 5,002 square miles, with something like 530 square miles of area of water surfaces—lakes, flats, and marshes. It appears, therefore, that the total area of water surfaces, flats, and marshes is about 10.6 per cent of the whole. The following lakes, ponds, and marshes are included in this catchment area: Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, Otisco, Cross, Onandaga, Cazenovia, Oneida, and Montezuma Marsh, together with a considerable number of miscellaneous small ponds and broad flat valleys.

To illustrate how these great natural reservoirs tend to prevent floods it may be mentioned that the configuration of Cayuga outlet, with relation to Clyde River, is such that frequently when there are heavy rainfalls in the catchment area of Clyde River the entire flood flow of Clyde River is discharged into Cayuga Lake, without affecting Seneca River below the mouth of Clyde River at all. It is undoubtedly due to this fact that fall floods on Oswego River are almost entirely unknown.

The evaporation of Oswego River catchment area is exceedingly large—about 28 inches—whence it results that the run-off from a mean annual rainfall of from 36 to 37 inches does not exceed about 9 or 10 inches. Owing to the large lake pondage the flood flows of this stream do not often exceed about 6 cubic feet per square mile per second.[a]

[a] See report to the United States Board of Engineers on Deep Waterways for extended discussion on *Oswego River*.

COMPUTATION OF ANNUAL RUN-OFF.

No general rule can be formulated for computing annual run-off. The formulas of Mr. Vermeule are excellent formulas of the purely empirical class, applying fairly well to many streams in the northeastern part of the United States, but they do not apply at all to streams of the Middle West and Far West. Nor do they apply to some streams in the northeastern section. Nevertheless, they take into account the ground water, and are the most useful formulas thus far devised. It may be mentioned that Mr. Vermeule especially disclaims any intention of working out any formulas applying outside of the State of New Jersey. His general formula is in the nature of a suggestion.

DISCREPANCIES IN COMPUTATION OF RUN-OFF.

In computing the run-off of various streams small discrepancies will continually appear, and when such do not exceed 1 to 2 inches they are outside the limit of discussion. The question does not admit of such minuteness as to permit the discussion of small differences, although a difference of 2 inches on several thousand square miles would be much more serious than on the usual municipal catchment area of from 20 to 100 square miles. The size of the catchment area should, therefore, in this particular be taken into account.

Moreover, the run-off of streams has thus far been almost universally overestimated. Only a few are really down to the actual fact. Probably in no department of professional work are there more things to be taken into account than here.

ACTUAL GAGINGS PREFERABLE TO GENERAL STUDIES.

While on the general subject of the computation of run-off the writer may repeat what he has said in his report to the United States Board of Engineers on Deep Waterways, viz:

> The data for estimating the water supply of a large canal, especially when on a large scale, should be based, when such data are available, upon actual gagings of streams, rather than on general considerations derived from study of the rainfall alone. An examination of a large number of estimates of canal water supplies, based on the usual method, shows that rainfall data alone are in close cases inadequate for solving a water-supply problem of the magnitude of the one now under consideration. When, however, actual gagings of the streams, extending over a sufficient number of years, are available, there is no reason why a water-supply problem on a large scale may not be worked out with the precision of a proposition in mathematics.

What is here said in regard to water supples for canals is equally true as regards all other water supplies, either municipal or for water power, etc. Further on in the same chapter it is stated:

> It is not intended to say, however, that rainfall data are not of use in a hydrologic discussion. When, as in the present case, in addition to stream gagings an

ries of such data are available, the argument is made doubly good and tration strengthened.

records of gagings are available the computation becomes le. It is merely a matter of simple addition and substraction. nplete data required in order to compute the safe possible stream are as follows:

catchment area.

rainfall of the minimum year, as well as for a series of

ound-water diagram of the stream or, lacking such, a dia- a neighboring stream lying in the same or a similar geo- nation, and, so far as possible, with similar conditions of n.

available storage capacity of the stream.

loss by water surface evaporation from the reservoirs, with an estimate of the loss by percolation.

ta required for ordinary computations may be frequently the totals of the storage, growing, and replenishing periods, when ground water is to be taken into account the monthly ld be given. The accompanying tables, Nos. 1 to 12, inclu- es 85–98), illustrate how such information may be placed in convenient use.

FORMULAS FOR RUN-OFF.

risk of being considered somewhat elementary the writer will ore important of the formulas for run-off, expressed in terms on the catchment area.

$$I_m = \frac{n \times Q \times 86400 \times 12}{A \times 640 \times 43560} \qquad (5)$$

we deduce,

$$I_m = \frac{n \times Q \times C_1}{A} \qquad (6)$$

$$I_y = \frac{Q \times C_2}{A} \qquad (7)$$

$$D = \frac{Q}{A} \qquad (8)$$

ge gallons per day into inches per month we have:

$$I_m = n \times G \times C_3 \qquad (9)$$

$$G = \frac{I_m}{n \times C_3}. \qquad (10)$$

In the reports of the United States Geological Survey, the discharge of streams is sometimes given in acre-feet per month. To reduce such to inches per month, we have, when total acre-feet are given,

$$I_m = \frac{B \times C_4}{A}. \tag{11}$$

In these formulas,

A=area of catchment in square miles.

B=total acre-feet per month.

D=cubic feet per second per square mile.

G=gallons per day.

I_m=inches in depth per month on the catchment area.

I_y=inches in depth per year on the catchment area.

n=number of days per month.

Q=cubic feet per second flowing from the catchment area, as determined by gagings.

$$C_1 = \text{constant} = \left(\frac{86400 \times 12}{640 \times 43560}\right).$$

$$C_2 = \text{constant} = \left(\frac{86400 \times 12 \times 365}{640 \times 43560}\right).$$

$$C_3 = \text{constant} = \left(\frac{12}{7.48 \times 640 \times 43560}\right).$$

$$C_4 = \text{constant} = \left(\frac{12}{640}\right).$$

The constants, C_1, C_2, C_3, and C_4, are left in form for logarithmic computation. For a given case, catchment area is constant, and A, in the final logarithmic form, will be combined with these.

MAXIMUM DISCHARGE FORMULA.

A considerable number of such formulas have been worked out, but the authors have taken into account so few of the controlling conditions, that they are, at the best, mostly only crude guides, and the writer long ago gave up their use, except in cases where only the roughest approximation was required. Two exceptions may, however, from the peculiar form of the coefficient, be briefly noted, viz:

$$\text{Dickens's formula, } D = C\sqrt{M^3}; \text{ and} \tag{12}$$

$$\text{Ryves's formula, } D = C\sqrt{M^2}. \tag{13}$$

In these formulas, D=discharge in cubic feet per second; C=a coefficient, depending for its value upon rainfall, soil, topographical slope, elevation, size of the stream, shape of the catchment, etc., and M=area of the catchment in square miles.

COEFFICIENT TABLE FOR REPRESENTATIVE AREAS.

In Mullins's Irrigation Manual[a] there are given tables for the value of the coefficients of these two formulas, together with the correspond-

[a] *Irrigation* Manual, by Lieut. Gen. J. Mullins (published for Madras Government), 1880.

ng depth in inches, drained off from the given areas, and the dis-charges in cubic feet per second. These two formulas are cited because they take into account the principle of the sliding coefficient, as does the Kutter formula, a principle which, all things considered, is the most useful thus far devised. It is true that maximum dis-charge formulas have been devised taking into account average slope, depth, and intensity of rainfall, area of the mountainous part of the watershed and area of flat part of the same in square miles, and length of stream from source to point of discharge. These formulas, however, also involve from one to two coefficients and become compli-cated in use without, it is believed, any special gain over the simpler expressions cited. The formulas of Dickens and Ryves, which com-prise within the coefficient C everything included in the more compli-cated formulas, were the forerunners of all formulas of this class.

COOLEY'S FORMULAS.

In an able paper[a] Mr. George W. Cooley, C. E., gives the following formulas for run-off:

For a watershed without lakes,

$$F=0.844\ LRC. \tag{14}$$

For a watershed with large lakes as receiving reservoirs,

$$F=(R+\frac{LRC}{W}-E)\times 0.844\ W. \tag{15}$$

In which, F=flow in cubic feet per second.
R=precipitation in feet.
L=land surface of watershed in square miles.
W=Water surface of reservoirs in square miles.
E=Evaporation in feet.
C=Coefficient of available rainfall.

The constant 0.844 is equal to the number of feet in a square mile ivided by the seconds in a year.

In these formulas the sliding coefficient is also recognized. The sults, however, are based on averages, although it seems clear ough that in either power or water supply works what is wanted is e minimum run-off for a year or a series of years. For instance, e minimum rainfall at Lake Minnetonka in 1889 was only 18.36 ches, while the maximum in 1892 was 37.90 inches, or a little more an double the minimum. It is evident enough to any person who as gaged streams extensively that the run-off in 1889 must have en very much less than in 1892. In the absence of statements as the amount of run-off in 1889, the writer can only estimate it, but

[a] Hydrology of the Lake Minnetonka watershed, by George W. Cooley, C. E.: Monthly Weather view, January, 1899.

he doubts if it were over 10 per cent to 12 per cent of the rainfall. Probably about 2 inches is not far from the mark. What is wanted, therefore, is a concise statement, not only in this case but in every other, of the run-off of the year or series of years of minimum rainfall.

DANGER OF USING AVERAGES.

The writer has dwelt upon the foregoing point somewhat because only a very few of the more advanced students of hydrology have thus far fully appreciated its importance. A very large proportion of all the papers and reports prepared in the last ten years have proceeded on the supposition that safe deductions could be made from an average run-off. It is needless to say that all such are, without exception, erroneous. What is wanted is a clear statement of the minimum, together with the longest period which such minimum may be expected to occupy. A study of the meteorological records of the State of New York shows that the minimum period may be expected frequently to extend over three years. In the writer's report to the United States Board of Engineers on Deep Waterways, in the chapter on the meteorology of New York and the relation of precipitation to run-off, a large number of specific cases are cited, but space will not be taken here to discuss them. This proposition is true for other regions than the State of New York.

DANGER OF USING PERCENTAGES.

A much greater danger arises from the use of percentage of rainfall appearing in run-off. In many reports and papers it is assumed that averages of a series of percentages can be safely taken. The following illustration, with five cases drawn from observation, may be taken to show that this is erroneous:

Run-off, per cent of rainfall.

Case.	Rainfall.	Run-off.	Per cent.
	Inches.	*Inches.*	
1	44.3	20.1	45.37
2	62.5	35	56
3	16.2	1.2	7.41
4	24.3	2.5	10.29
5	40.4	13.1	32.42
	187.7	71.9	5)151.49
			30.29

$$\text{Run-off} = \frac{71.9}{187.7} = 38.31$$

Difference = 8.02

As a corollary to the preceding proposition, it follows that the ratio between annual rainfall and run-off known as the "run-off coefficient or factor" is essentially misleading. A realization of this fact has led the writer, in his report to the United States Board of Engineers on Deep Waterways, to practically expurgate this statement, or anything approximating to it, from his report. The expressions "average run-off" and "percentage of the rainfall" do not appear.

Attention may also be again directed to the fact that the total run-off of a stream in any given year depends very largely on the run-off of what may be termed the "storage period." Usually about 0.75 to 0.85 of the total rainfall of this period appears as run-off in the stream, while for the summer, or growing period, not more than about 0.1 of the rainfall appears. This great difference is due to greater evaporation, as well as to the absorption of water by plants during this period. The total amount for the year which will appear as run-off in the stream will depend, therefore, very largely on whether or not the rainfall of the storage period—December to May, inclusive—is large or small. If the winter rainfall is relatively large, the run-off will also be relatively large, even though the total rainfall for the year is small. This fact must be taken into account in estimating the value of streams. Whether any given stream is low during the summer months or has then a well-sustained flow will depend very largely on the rainfall of the month of May. When the May rainfall is heavy enough to produce full ground water, the flow is likely to be well sustained, even though the rainfall is comparatively low during the summer months following. If, on the contrary, the May rainfall is so low as to leave a deficiency in ground water for that month, the flow will be low during the summer, even though the rainfall is large.

The foregoing also explains why for certain years the run-off of a stream may be relatively small, even with rainfall considerably above the average.

To more particularly illustrate this, assume a stream with, say, 6 inches of ground-water flow and further assume that on any convenient date the ground water is practically depleted. Under these circumstances, the 6 inches of ground water must fill up before any very large flow can occur. On the other hand, we may consider the sequence of the rainfall such as to leave full ground water, whence it results that there will be a much larger run-off, even though rainfall and other conditions are the same.

What is wanted in a stream, therefore, is as large a ground flow as possible, with small evaporation. That there are very great differences in streams in this respect may be easily seen by examining a series of tables of stream flow. It may be remarked that these two conditions are obtained only on a forested area, for proof of which see Bulletin No. 7, Department of Agriculture, Forest Influences.

EFFECT OF LOW GROUND WATER.

Moreover, when rainfall is below the mean for several months, the ground water may be expected to become continuously lower. This is a subject about which comparatively little is known, although the data are very important in estimating the permanency of a stream. Aside from Mr. Vermeule's, the most satisfactory discussion which the writer has seen is that of Mr. W. S. Auchincloss.[a] This paper, while too long to be abstracted, is nevertheless very interesting, because the author recognizes the limitations of averages. On page 10, after giving a table of the average rise of his sublake, he states:

> Since the table was built up from averages, we must not expect it to emphasize special variations, for the grouping of averages resembles the grouping of pictures in composite photography. The combination invariably brings out class likenesses to the exclusion of individual features. Thus the table loses sight of an extraordinary year like 1889—full of plus quantities—also seasons of drought, like 1894 and 1895. It, however, clearly shows that influx has a tendency to prevail between February and July, inclusive, and efflux to hold the mastery during the remaining months of the year.

Though this paper does not fully recognize the wide variation occurring at different localities, this is probably not due to oversight, but merely to the fact that the author was discussing a specific case. The observations recorded were made at Bryn Mawr, Pa. The paper is valuable and well worth the attention of students of hydrology.

VERMEULE'S FORMULAS.

These formulas are somewhat different from those previously considered. Mr. Vermeule claims to have discovered a relation between evaporation and mean annual temperature. For the relation between annual evaporation and annual precipitation on Sudbury, Croton, and Passaic rivers he gives the following:

$$E=15.50+0.16\ R, \tag{16}$$

In which E=the annual evaporation and R=the annual rainfall.

In the original publication of his formula, in the Report of the Geological Survey of New Jersey,[b] Mr. Vermeule allowed for other catchment areas an increase or decrease of 5 per cent from values given for evaporation on the Sudbury, Croton, and Passaic rivers. The following is his general formula for all streams:

$$E=(15.50+0.16\ R)\ (0.05\ T-1.48) \tag{17}$$

This, however, he states is merely a suggestion. His purpose is to deduce laws which hold for the State of New Jersey alone.

In these formulas the evaporation is taken to include all the various losses of water to which a catchment area is subject, including direct evaporation as well as water absorbed and transpired by plant growth, etc. Hence,

$$F\ (\text{run-off})=R-E. \tag{18}$$

---

[a] On Waters within the Earth and Laws of Rainflow, by W. S. Auchincloss, C. E. Philadelphia. 1897.

[b] *Report on* water supply, water power, the flow of streams, and attendant phenomena, by *C. C. Vermeule:* Final Report State Geologist of New Jersey, Vol. III. Trenton, 1894.

Mr. Vermeule gives the following formulas for the Sudbury, Croton, nd Passaic rivers:

$$\text{December–May, } E=4.20+0.12\ R; \tag{19}$$

$$\text{June–November, } E=11.30+0.20\ R. \tag{20}$$

These formulas take into account the fact that evaporation is low in e winter months and high during the summer.

Mr. Vermeule also gives the following formula for computing nthly evaporation from the monthly rainfall for Sudbury, Croton, d Passaic catchment areas:

[e=monthly evaporation; r monthly rainfall.]

ember	$e=0.42+0.10\ r$
uary	$e=0.27+0.10\ r$
ruary	$e=0.30+0.10\ r$
rch	$e=0.48+0.10\ r$
ril	$e=0.87+0.10\ r$
y	$e=1.87+0.20\ r$
ne	$e=2.50+0.25\ r$
ly	$e=3.00+0.30\ r$
gust	$e=2.62+0.25\ r$
tember	$e=1.63+0.20\ r$
tober	$e=0.88+0.12\ r$
vember	$e=0.66+0.10\ r$
Year	$e=15.50+0.16\ r$

(21)

To obtain the monthly evaporation for other streams the results tained are multiplied by the following:

$$(0.05\ T-1.48.)$$

In which T=mean annual temperature.

At this point Mr. Vermeule was confronted by the difficulty of ound storage. In regard to the effect of this it may be mentioned at, with rainfall above the average continuously for several years, ound water may be expected to stand above its average height, lding to streams the maximum flow possible to ground water. On e other hand, when the rainfall is below the average for a number years ground-water flow will be lower, becoming less and less as e rainfall approaches the minimum. It is very important that this t be taken into account, because without it one is certain to fall o error. The formulas for average depletion may be given as llows:

$$d_2=d_1+e+f-r; \tag{22}$$

$$d=\frac{f}{2}+d_1-\frac{r-e}{2}. \tag{23}$$

In which d_1 and d_2=depletion at end of previous month and for the nth under consideration; d=average depletion; e and r=monthly aporation and monthly rainfall, respectively, and f=computed nthly flow.

The foregoing does not fully express the use of these formulas, but all that is wanted at this time is an illustration of methods, this ief account may be deemed sufficient.

Mr. Vermeule gives a diagram showing ground flow for the several different streams mentioned for a given depletion, which is to be used in conjunction with the foregoing formulas. In his opinion the diagrams present advantages over a ground-flow formula with varying constants and coefficients for different streams, being more readily compared and insuring greater accuracy. Later, in his report on forests,[a] Mr. Vermeule modifies his formula, as follows:

$$E=(11+0.29\ R)\ M. \qquad (24$$

In which E=evaporation, R=rainfall, and M is a factor depending upon the mean temperature of the atmosphere. The writer understands Mr. Vermeule to say that this is also an expression for annual evaporation.

Values of M for given mean annual temperatures are as follows:

40°, 0.77; 41°, 0.79; 42°, 0.82; 43°, 0.85; 44°, 0.88; 45°, 0.91; 46° 0.94; 47°, 0.97; 48°, 1; 49°, 1.03; 50°, 1.07; 51°, 1.10; 52°, 1.14; 53° 1.18; 54°, 1.22; 55°, 1.26; 56°, 1.30; 57°, 1.34; 58°, 1.39; 59°, 1.43; 60° 1.47; 61°, 1.51.

In a table on page 149 of the Report on Forests Mr. Vermeule compares observed annual evaporation with computed annual evaporation. The following are some of the differences which appear:

On the Genesee River the observed annual evaporation is 27. inches; computed annual evaporation, 20.6 inches; the observed annual evaporation, therefore, is 6.6 inches, or 32 per cent, greater than the estimated annual evaporation. On the Musconetcong River the observed, as compared with the computed evaporation, is 13 per cent less; on the Pequest it is 17 per cent less; on the Paulinskill it is 14 per cent less; on the Tohickon, 32 per cent less; on the Neshaminy, 16 per cent less; on the Perkiomen, 17 per cent less; on the Desplaines, 21 per cent greater; on the Kansas, 15 per cent greater; on the Upper Hudson, 10 per cent greater; on Hemlock Lake, 18 per cent less; on the Potomac, 17 per cent less; on the Savannah, 13 per cent less. For the rest of the streams cited in the table the agreement is closer than this.

The observed annual evaporation is 32 per cent greater than the computed annual evaporation on the Genesee River and 32 per cent less on Tohickon Creek—a range of 64 per cent. Somewhat similar differences are found on other streams where the gagings are approximately right. As to the gagings referred to in the report on forests the writer will show farther on in this paper that gagings of Genesee and Hudson rivers are, on the whole, probably the best thus far made in the United States. Tohickon, Neshaminy, and Perkiomen creeks have been gaged by Francis weirs, and are, with the exception of Tohickon, considered approximately right. The difficulty here is probably in the flood flows. The writer understan

[a] *Report on forests*, by C. C. Vermeule: Ann. Rept. State Geologist New Jersey for year 1900. *Trenton, 1900.*

that Mr. Vermeule used the Francis formula for a sharp-crested weir. The gagings of Sudbury, Cochituate, and Mystic rivers have been reduced, it is believed, by Mr. Francis's formula for the Merrimac dam. As to Desplaines River, a discharge curve determined by current meter has, it is believed, been applied.[a] The English streams cited, Lea, Wandle, Thames, etc., have probably been gaged by a sharp-crested weir, and the others mostly by the current meter and a rating table.

RUSSELL'S FORMULAS.

Mr. Thomas Russell[b] gives the following formulas for the run-off of the Ohio, Upper Mississippi, and Upper and Middle Missouri valleys, in terms of the annual rainfall. For the Ohio River the formula is as follows:

$$O=0.600+0.95\ R-0.90\ R\ (0.975\ e-0.421\ e^2+0.626\ e^3). \quad (25)$$

For the Upper Mississippi it is:

$$O=0.50+0.93\ R-0.88\ R\ (1.131\ e-0.383\ e^2). \quad (26)$$

For the Upper and Middle Missouri it is:

$$O=0.12+0.98\ R-0.93\ R\ (0.91\ e-0.220\ e^2+0.009\ e^3). \quad (27)$$

In these formulas R is the rainfall for the month in cubic miles; e is the quantity of water required to saturate the air at any time, equal to the difference between what the air contains and the amount if it was saturated; and O is the outflow or run-off.

These formulas are interesting in the present connection, because they recognize the fact that every stream must have its own formula. The variation in run-off on the Ohio, Mississippi, and Missouri rivers will be observed on inspection of the formulas. Like all formulas of this class they are subject to considerable variation. In the month of October, 1881, the computed outflow of Missouri River was 4.9 cubic miles and the observed flow was 1.6 cubic miles, a difference of 3.3 cubic miles.

RELATION BETWEEN CATCHMENT AREA AND MAXIMUM, MINIMUM, AND MEAN RUN-OFF.

It is quite common for hydrologists to assume that there is a relation between catchment area and maximum, minimum, and mean run-off, the general proposition being that mean annual run-off varies inversely as the size of the catchment, and that maximum run-off, or flood flow, varies directly as the size of the catchment.

In order to gain some idea as to the applicability of this proposition, the résumé of discharge data, in the Twentieth Annual Report of the

[a] Data pertaining to rainfall and stream flow, by Thomas T. Johnston: Jour. Western Soc. Engrs., Vol. I, No. 3, June, 1896.

[b] Rainfall and river outflow in the Mississippi Valley, by Thomas Russell: Ann. Rept. Chief Signal Officer for the year 1889, Part I, Appendix 14.

United States Geological Survey, pages 46–64, has been examined. This table includes about 225 streams in various portions of the United States, with records ranging from 18 to 20 years in length to 1 year. A few of the best-known streams—as, for instance, the Croton and Sudbury—are not given in detail, although the large number included in this table, it is believed, is sufficient to settle definitely this question. Only a very few of the results will be referred to here.

In the first place, it appears certain that with equal rainfall there is no very definite relation between size of catchment area and mean annual run-off. For instance, the Kennebec, at Waterville, Me. with a catchment area of 4,410 square miles, has a mean annual run off for 6 years of 22.4 inches. The Cobbosseecontee, at Gardiner, Me. with a catchment area of 230 square miles, has a mean annual run-off for 6 years of 18.5 inches. The Androscoggin, at Rumford Falls, Me. with a catchment area of 2,220 square miles, has for 6 years a mean annual run-off of 24.2 inches. The Presumpscot, at Sebago Lake Me, with a catchment of 470 square miles, has a mean annual run off for 11 years of 21 inches. The Merrimac, at Lawrence, Mass. with a catchment area of 4,553 square miles, has a mean annual run-off for 9 years of 21.3 inches. Aside from the Androscoggin River these five streams support the proposition that the run-off varies in some degree directly as the drainage area instead of inversely.

As to the maximum run-off, or flood flow, there is apparently some slight relation, although even this is less definite than has usually been assumed.

As to minimum run-off, there is apparently no relation, extremely small flows happening on large streams as well as on the smallest. There is, however, much more definitely a relation between the run-off and the rainfall, run-off increasing as rainfall increases, and conversely.

As regards the division of streams into classes in proportion to size of catchment area, it appears, therefore, that aside from maximum run-off one is not, on present information, justified in such classification, and even in cases of flood flow it is quite probable that there are other considerations of such importance as to render a classification of this character inexpedient.

In the rivers for which data are given in this paper the catchment areas vary from 18.9 square miles for Lake Cochituate to 10,234 square miles for the Connecticut River. Since there is no very definite relation between size of catchment and run-off there is no reason why the comparison may not be made of streams having such large difference in size of catchment. For some streams—as, for instance, Pequannock River—where the slopes are very steep, the run-off is somewhat higher than it would be with other conditions the same, but with flatter slopes. But generally the degree of forestation and other elements exercise so much more important an influence that a comparison, without regard to size of catchment area, may be legitimately

made. Nevertheless, this proposition is possibly debatable, and for the present the conclusions drawn are tentative merely.

THE EXTREME LOW-WATER PERIOD.

In the discussion of Tables Nos. 1–12, inclusive, the writer has given the low water of the minimum year, but this does not usually include the extreme low-water period, which is in almost every case much more than one year. Space will not be taken to show the extreme low-water periods of all these tables. It is considered that illustrations from Muskingum and Genesee rivers are sufficient. This information is given in Tables Nos. 14 and 15.

On the Muskingum River three low-water periods have occurred during the time covered by the gagings. The first was from December, 1887, to November, 1889, inclusive, a period of twenty-four months, during which the total run-off was 18.55 inches, or if we assume a reservoir on said stream of 20 square miles water surface, the total net run-off becomes 18.15 inches. The computations of evaporation, etc., for such a reservoir, neglecting variation in water surface, are as follows. Assume an annual evaporation of 40 inches and with distribution for the several months as per column 1 in the following table. Since the water surface area is 20 square miles, it becomes 20/5828 of the whole, or 1/292. Hence, water surface evaporation is 1/292 of 40 inches, and making the computation for each month, we have the quantities as per column 2:

Total evaporation and evaporation per square mile of water surface in Muskingum Basin.

Month.	1. Total evaporation.	2. Evaporation per square mile of water surface.
January	1.00	0.0034
February	1.10	.0037
March	1.70	.0058
April	3.00	.01029
May	4.60	.01578
June	5.65	.01938
July	6.10	.02092
August	5.60	.01921
September	4.15	.01423
October	3.35	.01149
November	2.25	.00772
December	1.50	.00514
	40.00	

With some allowance for percolation, leakage, etc., the total is taken at 0.40 of an inch per year. Analyzing the first period, we find that for 24 months there was an average flow of 0.76 inch per month, for 12 months an average flow of 0.67 inch, and for 9 months an average flow of 0.43 inch.

The second low-water period was from May, 1891, to January, 1893, inclusive, a period of 21 months, during which time the net run-off was 17.2 inches, yielding for the whole 21 months an average of 0.82 inch and for 7 months an average of 0.36 inch.

The most extreme low-water period was from April, 1894, to November, 1895, inclusive, a period of 20 months, during which time the net run-off did not exceed under the assumed conditions 7.09 inches. The average run-off for 20 months was 0.354 inch and for 7 months 0.116 inch.

On Genesee River there have been two low-water periods during the time covered by the gagings. The first was from June, 1894, to February, 1896, a period of 21 months, during which time there was a gross run-off of 13.02 inches. Evaporation has been computed for a proposed reservoir of 12.4 square miles water-surface area, with allowance for actual height of water during the different months. On this basis and with a small allowance for percolation, leakage, etc., the total evaporation loss for the 21 months becomes 0.65 inch, leaving a net run-off of 12.37 inches. The average run-off for 21 months was 0.59 inch, or, if we assume 1.43 inches left in reservoir at end of period, the average allowable run-off becomes 0.52 inch. For 10 months, with some allowance, the average run-off is 0.30 inch and for 7 months 0.10 inch.

The second period was from June, 1896, to December, 1897, a period of 19 months, during which time the net run-off was 13.24 inches. The average run-off for 19 months, with 1.24 inches left in reservoir at end of the period, was 0.63 inch; for 8 months, 0.31 inch, and for 6 months, 0.17 inch. These figures, without being exhaustive, show that Genesee River is a somewhat better water yielder than Muskingum River.

A large number of other interesting and valuable tabulations could be drawn from these data, especially those relating to storage. But since this element is not specially considered in this paper they are not given. In any case, enough has been said to sustain the statement that streams vary, not only as regards their total capability of yielding water, but as regards its distribution. In order to develop a stream to its maximum capacity for either water power or municipal purposes it is absolutely indispensable to have a series of carefully prepared gagings. Lacking these, there should be gathered as long a rainfall record as possible, from which, by comparison, the approximate run-off of the stream may be computed. A carefully taken series of gagings is, however, in every way preferable.

VARIATION IN WEIR MEASUREMENTS.

The writer has shown[a] the considerable variation in weir measurements due to difference in form of weir alone. So great are these that any conclusions based upon the data of sharp-crested weirs applied to other forms are extremely unsatisfactory. In one case of a flat-crested weir, the flow at a given depth is only 75 per cent of that it is over a sharp-crested weir. Variations of from 5 per cent to 20 per cent are common, as may be easily observed by examining the tables in the paper cited.

In view of the importance which gagings are now shown to bear in estimating the value of a stream for water power or city water supply, in future every statement of stream flow should be accompanied by a concise statement of the method of gaging used, thus permitting hydrologists to judge of the general reliability of the method. Had this been done in the past, some of the uncertainty which now attaches to many gaging records would undoubtedly be removed.

GENESEE AND HUDSON GAGINGS REDUCED TO SHARP-CRESTED WEIR MEASUREMENTS.

The writer has shown in another place that Genesee River gagings which were made by him have been reduced to sharp-crested weir measurements. As to the Hudson gagings, Pl. CXXVII in the Report to the United States Board of Engineers on Deep Waterways may be cited. This plate is a comparison of the discharge over weirs by different formulas, and it appears from it that Mullins's formula for a flat-crested weir, which has been used for the Upper Hudson gagings, at a depth of 4 feet gives results less than Francis's formula for a sharp-crested weir by about 10 per cent. However, in order to simplify the computation and to avoid velocity of approach, the width of the crest was taken at 5 feet. Again, the crest at Mechanicville is not flat, but is slightly sloping backward. The sloping front probably affects the flow to increase it somewhat. There are also flashboards used during low water, which are properly computed by Francis's formula for a sharp-crested weir. These several elements undoubtedly make the problem somewhat complicated, but taking everything into account it is probable that the results as computed are not far from right. They may, however, be in error as much as 2 inches per year.[b]

As regards the relation between mean annual temperature and evaporation, the questions raised by Mr. Vermeule are very interesting and have received considerable study from the writer ever since the publication of Mr. Vermeule's report in 1894. This study has been specially directed toward determining whether there was any

[a] On the flow of water over dams: Trans. Am. Soc. C. E., Vol. XLIV, p. 220.

[b] See the diagrams of Hudson and Genesee rivers on this point.

way of showing by diagrams, definitely, that any such relation really existed. A concise résumé of such study will now be given.

EVAPORATION.

FITZGERALD'S FORMULA FOR EVAPORATION.

In the first place we may consider Mr. FitzGerald's formula for evaporation,[a] which is:

$$E=\frac{(V-r)\left(1+\frac{W}{2}\right)}{60}. \qquad (28)$$

In this formula V=the maximum force of vapor in inches of mercury corresponding to the temperature of the water; r=the force of vapor present in the air; W=the velocity of the wind in miles per hour; and E=the evaporation in inches of depth per hour. It can be shown that there is going on nearly always a condensation of moisture from the air upon any water surface. At the same time there is going on a loss of moisture from the water surface by evaporation. The intensity of both these operations depends upon the difference in temperature between the air and any water surface with which it may be in contact. When the temperature of air and water is the same both processes stop. Evaporation is, therefore, in effect the measure of the difference of these two exchanges. The velocity of the wind is also seen to exert a very decided effect on the intensity of evaporation.

In the foregoing formula, r, the force of vapor present in the air is computed by the following:

$$r=V-\frac{0.480\,(t-t')}{689-t'}h, \qquad (29)$$

In which r=the force of vapor in the air at the time of the observation;

t=the temperature of the air in centigrade degrees, indicated by the dry thermometer;

t'=the temperature of evaporation given by the wet thermometer;

V=the force of vapor in a saturated air at the temperature t'; and

h=the height of the barometer.

There is no difference between evaporation from a water surface and evaporation from land, except that on a water surface it goes on continuously, while on land evaporation may be interrupted from lack of something to evaporate. The preceding formula shows that the force of vapor is dependent upon the difference of the dry and wet bulb thermometers, and not in any degree upon the mean annual temperature.

---

[a] Trans. Am. Soc. C. E., Vol. XV, pp. 581-646.

EVAPORATION RELATIONS.

Prof. Cleveland Abbe[a] gives the following relations of evaporation, established by Prof. Thomas Tate:

1) Other things being the same, the rate of evaporation is nearly proportional he difference of the temperatures indicated by the wet-bulb and dry-bulb mometers.

2) Other things being the same, the augmentation of evaporation due to air in ion is nearly proportional to the velocity of the wind.

3) Other things being the same, the evaporation is nearly inversely proportional to the pressure of the atmosphere.

4) The rate of evaporation of moisture from damp, porous substances of the e material is proportional to the extent of the surface presented to the air, iout regard to the relative thickness of the substances.

5) The rate of evaporation from different substances mainly depends upon the ghness of, or inequalities on, their surfaces, the evaporation going on most dly from the roughest or most uneven surfaces; in fact, the best radiators are best vaporizers of moisture.

6) The evaporation from equal surfaces composed of the same material is the e, or very nearly the same, in a quiescent atmosphere, whatever may be the nation of the surfaces; thus a horizontal plate with its damp face upward orates as much as one with its damp face downward.

7) The rate of evaporation from a damp surface (namely, a horizontal surface ng upward) is very much affected by the elevation at which the surface is ed above the ground.

8) The rate of evaporation is affected by the radiation of surrounding bodies.

9) The diffusion of vapor from a damp surface through a variable column of aries (approximately) in the inverse ratio of the depth of the column, the perature being constant.

10) The amount of vapor diffused varies directly as the tension of the vapor at ren temperature, and inversely as the depth of the column of air through ch the vapor has to pass.

11) The time in which a given volume of dry air becomes saturated with vapor, turated within a given percentage, is nearly independent of the temperature e source of vapor is constant.

12) The times in which different volumes of dry air become saturated with ry vapor, or saturated within a given per cent, are nearly proportional to volumes.

13) The vapor already formed diffuses itself in the atmosphere much more dly than it is formed from the surface of the water. (This assumes, of course, there are no convection currents of air to affect the evaporation or the diffion.)

EFFECT OF WIND AND OTHER METEOROLOGICAL ELEMENTS.

That the velocity of the wind must have a very material effect on evaporation, and hence upon the run-off of streams, is at once parent on inspection of Mr. FitzGerald's evaporation formula, given preceding chapter. Again, on examining the annual summaries he report of the Chief of the Weather Bureau the average yearly city of wind is found to vary from about 3 miles to 16 or 18 miles.

---

[a] reparatory studies for deductive methods in storm and weather predictions, by Prof. Cleve-Abbe: Ann. Rept. Chief Signal Officer for 1889, Part I, Appendix 15.

With other conditions the same, evaporation will be much larger with a higher wind velocity.

The preceding summary of evaporation relations further shows that evaporation will vary in some degrees in proportion to pressure, temperature, moisture—which may be taken to include dew-point, relative humidity, vapor pressure, precipitation, and cloudiness—and finally, in proportion to average velocity of the wind. It may also be expected to vary in some degree in proportion to electrical phenomena—thunderstorms, auroras, etc.—but as yet we know so little about these that they can be no more than mentioned. The writer, however, believes that studies in the direction here indicated would be very prolific of results. For this purpose two or three stations observing all the elements herein enumerated, should be established in each catchment area.

In the present study an attempt has been made to correlate these elements with the run-off, but, aside from the rainfall, the data are too indefinite for satisfactory results. It is for these reasons, with others, that the writer is able to give only tentative conclusions in regard to the relation of rainfall to the run-off of streams.

PERSISTENCY OF RATE OF EVAPORATION.

The persistency of the amount of evaporation for any given stream at about the same figure through long periods of time was first pointed out by Messrs. Lawes, Gilbert, and Warrington in their classic paper, On the Amount and Composition of Rain and Drainage Water Collected at Rothampsted, published in the Journal of the Royal Agricultural Society of England for 1881. As to why evaporation exhibits such persistency these distinguished authors consider largely due to the fact that the two principal conditions which determine large evaporation—namely, excessive heat and abundant rain—very rarely occur together. The result is, especially in the English climate, a balance of conditions unfavorable to large evaporation. In a wet season, when the soil is kept well supplied with water, there is at the same time an atmosphere more or less saturated, with little absence of sunshine; while in dry seasons the scarcity of rain results in great dryness of the soil, with scant, slow evaporation.[a]

NEGATIVE EVAPORATION.

In a strictly scientific sense this term is taken to mean that when the temperature of the evaporating surface is lower than the dew point, water is deposited on that surface. As regards the rainfall, run-off, and evaporation tables, herewith included, negative evaporation means that the run-off for certain months is greater than the rainfall. Sometimes this may legitimately happen when a heavy rain

[a] Since the persistency of evaporation has been extensively discussed in the writer's paper *on Stream flow* in relation to forests (see footnote on p. 54), it is merely touched on here.

fall comes at the end of the month, or when, with much snowfall, the temperature of the month is mostly below freezing. In order to show as much as possible in regard thereto, the writer gives the detail for each of the 12 tables, together with a tentative view as to the real significance of the so-called negative evaporation.

On Muskingum River, during the 8 years gaged, negative evaporation is shown only twice for one month.

On Genesee River the detailed tabulation shows negative evaporation 5 times for one month and once for two consecutive months, a total of 7 months in all.

On Croton River, for the entire period of 32 years, negative evaporation is shown 29 times for one month and 6 times for two consecutive months, a total of 41 months in all.

On Lake Cochituate negative evaporation is shown 24 times for one month, 3 times for two consecutive months, and twice for three consecutive months, a total of 36 months in all. Negative evaporation is also shown once for the entire storage period in 1891.

On Sudbury River it is shown 16 times for one month, 9 times for two consecutive months, and 3 times for three consecutive months, a total of 43 months in all.

On Mystic Lake it is shown 12 times for one month, twice for two consecutive months, once for three consecutive months, and once for four consecutive months, a total of 23 months in all.

On Neshaminy Creek negative evaporation is shown 6 times for one month, 5 times for two consecutive months, and once for three consecutive months, a total of 19 months in all.

On Perkiomen Creek negative evaporation is shown 10 times for one month, twice for two consecutive months, and twice for three consecutive months, a total of 20 months.

On Tohickon Creek it is shown 11 times for one month, 4 times for two consecutive months, twice for three consecutive months, and once for four consecutive months, a total of 29 months. The year 1884 shows a negative evaporation of 1.21 inches for the entire storage period, and the year 1899 a negative evaporation of 2.37 inches for the entire storage period. This latter is so large that it has seemed best to reject the year 1899. Probably the year 1884 should also have been rejected, but it has been allowed to remain.

On Hudson River negative evaporation is shown 7 times for one month and 4 times for two consecutive months, a total of 15 months.

On Pequannock River it is shown 9 times for one month and 5 times for two consecutive months, a total of 19 months.

On Connecticut River negative evaporation is shown 6 times for one month, 9 times for two consecutive months, and once for three consecutive months, a total of 27 months. The year 1873 shows −3.64 inches in the storage period, and for the year 1874 the positive evaporation of the storage period is only 0.04 inch; for 1876 it is for

the same period —2.24 inches. The years 1873, 1874, and 1876 have been rejected in computing the means.

The writer has no doubt that, except in cold climates, when negative evaporation occurs for three or more consecutive months, there is an error in the gagings. He also doubts their accuracy somewhat when negative evaporation appears for two consecutive months. As regards the storage period, there is no difficulty in accepting it for one month as true, because rainfall or snowfall at the end of the month can be easily carried over to the next. This is also true sometimes for two months, but for the present it seems quite doubtful that other than in exceedingly rare cases would negative evaporation occur for three consecutive months. Its occurrence for six consecutive months, or for the entire storage period, is believed to be impossible. It may, however, be again pointed out that its occurrence renders an attempt at monthly diagrams showing the relation between rainfall and run-off absurd.

Assuming that the foregoing propositions are reasonably true, it follows that the frequency of the occurrence of negative evaporation in gaging records may be in some degree a criterion as to their accuracy. The writer, however, does not wish to urge this very strongly, but merely to point it out as a possibility.

In reference to Tables Nos. 1–12, inclusive, it may be stated that these are really all that are available for such a discussion. There are several stream-flow records which are nearly as accurate as any herein included, but unfortunately they were not accompanied by records of rainfall, and the considerable labor of compiling and reducing these has prevented their use. There are also some records, with rainfall included, of which the gagings are not considered very reliable, and which, for the present, are left untouched on that account.

In a report on the flow of the river Thames, by A. R. Binnie, chief engineer of the London county council,[a] the matter of negative evaporation is elaborately discussed, and in order to obtain all the information possible about it Mr. Binnie applied to George J. Symons, F. R. S., to assist him in arriving at some approximate idea on the subject. Mr. Symons submitted an exceedingly lucid and conclusive report. Eleven distinct cases of negative evaporation were submitted to him for study and comment. In regard to these he arrived at the following conclusions:

(1) Under normal conditions a fall of rain will increase the flow at Teddington weir on the second day after it falls.

(2) Under normal conditions the water running off from any given fall of rain will all reach Teddington weir before the tenth subsequent day.

(3) In the winter an interval of two months, or in extreme cases even more, may elapse between the precipitation of moisture from the clouds and its flow over Teddington weir.

[a] Report on the Flow of the River Thames, by A. R. Binnie. Publication of the London County Council, dated November 1, 1882.

As a consequence of (2) it is clear that a heavy rainfall on the last rs of any month may not appear at the point of gaging until the xt month. Mr. Symons also states that the one great fact which s been impressed upon him by these investigations is the great ect of winter frosts in regulating the flow of the river Thames and mitigating winter floods.

These conclusions are more especially intended to apply to the river ames. Hence, while it is true that so-called negative evaporation ists on all of the streams considered, the conditions are neverthe-s very different, and in the United States the effect of holding back e flow of streams by frosts is in very many cases to precipitate a od of water later on. This element would hardly be considered th us as either a river regulator or as mitigating floods.

GROUND WATER.

MOVEMENTS OF GROUND WATER.

In an extensive paper Prof. F. H. King has very clearly defined any of the underlying principles covering the movements of ground ater.[a] In the beginning of his paper Professor King remarks that ere is no single substance entering into the structure of the earth hich has played and is playing so important a part as water. It netrates the soils, sands, and rocks of the land areas in such large antities that sand and sandstones lying below water level may ntain as high as 38 per cent of their volume of water. Even the antity stored in soil, gravel, and clay is very large. The water a saturated soil or clay may range from 22 per cent up to 40 and en 50 per cent of its dry weight. The following table, giving the ter capacity of undisturbed soils when lying below the plane of turation, shows the amount of water which may be contained in rious soils under natural conditions:

Water capacity of undisturbed soils.

Kind of soil.	Depth of layer.	Per cent of water.	Inches of water.
	Inches.		
rly loam	0 to 12	41.3	5.88
ddish clay	12 to 24	28.1	5.03
Do	24 to 36	28.4	5.07
y with sand	36 to 48	24.8	4.67
ry fine sand	48 to 60	17.4	3.76
Total			24.41

[a] Principles and conditions of the movements of ground water, by F. H. King: Nineteenth Ann. Rept. U. S. Geol. Survey, Part II.

Professor King states that there are many reasons for believ that water penetrates the fissures and interstices of the earth depths even exceeding 10,000 feet. If the waters so inclosed form larger part than 1 per cent of the weight of the material, with a s cific gravity of 2.65, the amount of inclosed water would be suffic to form an envelope 265 feet deep.

Moreover, Professor King's observations show that ground wat very easily disturbed and is constantly in motion. It responds r ily to changes in barometer, temperature, etc. It is evident t these movements are not only closely related to the rainfall, source of ground water, but that the run-off of streams is consider influenced thereby.

GROWTH OF STREAMS BY ACCESSION OF GROUND WATER.

It is evident, without special discussion, that streams winc through the thread of a valley must receive accession to their umes little by little as they move along. A few such, cited by l fessor King, may be mentioned.

1. The Los Angeles River, in California, was measured in winter of 1897–98, showing that in a distance of 59,088 feet (1 miles) the river increased in volume from 20.41 cubic feet per sec to about 80 cubic feet per second. The width of the river will a age perhaps 40 feet, and adding to this 5 feet on each bank, thro which water may enter the stream, we have a seepage surface o square feet per linear foot of length, whence we have a total seep surface of 2,954,400 square feet. We have then for this partic case an average rate of seepage of 0.0000203 of a cubic foot per sq foot per second.

This computation is made without reference to gradient, whic unknown.

A profile of the growth of the Los Angeles River is also gi which shows that the rate of accession is not uniform, but that m the larger portion of it takes place in the upper 47 per cent of the t length.

2. The West Los Angeles Water Company has a flume about 4 feet long sunk below the normal level of the ground water for purpose of collecting the same and delivering it at the surface lo down the valley. The flume is described as being rectangular cross section, 4 feet deep and 5 feet wide, with open bottom, covered and provided with wooden sides.

On January 21, 1897, the flume was discharging 7.2 cubic feet second; on November 19, 1896, 7.29 cubic feet per second; on Ma 1, 1896, 8.5 cubic feet per second; on November 23, 1895, it is sai have discharged 10.1 cubic feet per second, but in April, 1898, it discharging 6.2 cubic feet per second.

3. The rate of seepage into the infiltration pipes of the Cry

Springs Land and Water Company may be mentioned. This system consists of an east-and-west line of infiltration pipes sunk below the normal level of the ground water of the river valley, which join in their lower portion, when they deliver the water collected by them to the surface. The pipes are glazed sewer tile, laid double upon boards in the bottom of a ditch, the space immediately around them being filled with coarse gravel and sand, while above the gravel the cut is filled with material from the excavation. The east infiltration line has a total length of double tile consisting of 1,343 feet of 24-inch tile, 300 feet of 20-inch tile, 1,385 feet of 15½-inch tile, and 619 feet of 12-inch tile, making a total of 3,647 feet of double line. The west infiltration line, also double, has a measured length of 1,721 feet, all of 15-inch pipe.

The water discharged from the system on February 1, 1898, was 9 cubic feet per second, or a mean rate of 0.001677 of a cubic foot per second for each linear foot of length.

Professor King's paper includes the discussion of very many questions of great practical importance—as, for instance, the rate of filtration of water through soil, percolation of water into undisturbed field soil, rate of lateral flow through sands, time required to lower the ground-water level of a system of infiltration pipes, rate of flow of water into wells, flow of water into driven-well points, rate of pumping from driven well compared with rate from open well, and many others which, however, are not referred to here from lack of space. The paper is worthy of close attention from everybody interested in ground water.

The paper also includes a concise summary of what has been done by a number of European observers. A few papers on ground water have appeared since the publication of Professor King's, which, however, the writer has not seen.

In connection with the studies of Professor King, Prof. Charles S. Slichter undertook a theoretical investigation of the motion of ground water, and his paper also appears in the Nineteenth Annual Report of the United States Geological Survey.[a]

In this paper Professor Slichter studies the question mostly from the mathematical point of view. As an example of the nature of the problems touched by him the following may be cited:

Given, a uniform bed of unfissured sandstone 100 feet thick, lying between impervious layers and dipping 5 feet per mile; given, further, (*a*) a uniform temperature of 10° C.; (*b*) a pore space of 30 per cent; (*c*) an effective size of grain of 0.15 mm.; (*d*) an effective head of 10 feet, and, (*e*) supposing no cementing or clogging material between grains; required, the possible discharge in cubic feet per minute per foot of vertical section into a vertical fissure extending at right angles to the dip and constantly filled with water, when the fissure is 20, 40, 60, 80, 100, 120, 140, 160, 180, and 200 miles from the border of the collecting area.

[a] Theoretical investigation of the motion of ground waters, by Prof. Chas. S. Slichter: Nineteenth Ann. Rept. U. S. Geol. Survey (1897-98), Part II.

The rainfall on the catchment area is sufficient to maintain a constant overfl across its border.

The paper concludes with a list of about 80 titles of papers ground water and related topics.

RELATION OF GEOLOGIC STRUCTURE TO RUN-OFF.

It is somewhat uncertain whether difference in soil due to differen in character of rocks has much influence on the run-off, althou casually it appears that sandy soils, from their porousness, do cons erably affect the result. Recent studies of this subject have sho (1) that in many river basins the annual run-off stands in a nea constant relation to the rainfall, and (2) that this constancy is m marked when the excess rainfall above a certain minimum ann depth is considered. This latter statement is equivalent to sayi that if the yearly rainfall is less than such minimum depth little no run-off will take place.

The general truth of this proposition is shown by many Weste streams where the run-off is little or nothing. In New Jersey inches of rain during the summer season produce a run-off of inches, though others have stated a somewhat different relation. the State of New York from 1.7 to 2 inches may be considered t general range. As to the amount of rain required to produce a run-off at all, from 12.5 to 16.5 inches have been given. For this mi mum many Western streams do not run more than 0.25 to 0.5 in and some even are perfectly dry. These statements indicate that t character of the soil, nature of vegetation, the elevation, etc., are comparatively small importance as regards relation between the yea volumes of rainfall and run-off. If, however, we consider the rainf and run-off of the several periods, as shown by the accompanyi tables, it is not entirely certain that these propositions are other th approximately true. The weight of evidence indeed is, on the who negative. Mr. Vermeule is disposed to attribute nearly all of t differences between streams to difference in geology, and according gives a geologic classification for the New Jersey streams. M Vermeule says:

> As a rule, the watersheds which lie upon the same geological formation will found to have a strong resemblance, both in the character of flow and in t chemical composition of the waters.

Yet, as will be shown later, the Genesee and Oswego rivers, t streams with approximately the same run-off, lie mostly in differe geologic formations. As regards quality of soils, Mr. Vermeule al says:

> It may be inferred that the kind of soil has much less to do with the amount evaporation than has the temperature.

As regards the relation between geology and run-off, it is undoubtedly complicated, although it is interesting to note that in the Sta

New York streams which flow from the north into Mohawk River, ter crossing over a narrow strip of Trenton limestone and Calciferr sand rock, and which head in the Laurentian granite of the dirondacks, have larger flows than those coming to the Mohawk om the south, which lie mostly in the horizon of the Hamilton ales, the headwaters of some of them—as for instance, Schoharie reek—being in the sandstones of the Chemung and Portage groups. their lower reaches they cross over the sandstones and shales of e Hudson and Utica groups, with narrow strips of Helderberg mestone, Oriskany sandstone, and Onandaga limestone.

However, there is another consideration. The headwaters of the treams to the north of the Mohawk nearly all lie in a region heavily mbered—some of it is still primeval forest—while those to the south re from a highly cultivated country, practically deforested.

We may now consider the case of Genesee and Oswego rivers, rerring to the large geologic map of the State of New York, pubshed in 1894, by James Hall, in cooperation with the U. S. Geological urvey.

Genesee River has an average rainfall of about 40 inches and Oswego iver of about 37 inches. That portion of Genesee River which has een gaged lies almost entirely in the shales and sandstones of the ortage and Chemung groups. Oswego River, on the contrary, lies n the horizon of the Portage sandstones and shales, Hamilton shales, nandaga and Helderberg limestones, Oriskany sandstone, the rocks f the Salina or Salt group, the Lockport limestone, Clinton limetone and shales, Medina sandstones, and Utica sandstones and hales, including the Oswego sandstone. The Chemung, Portage, and lamilton formations have a wide outcrop, while the Onandaga, riskany, and Helderberg are comparatively narrow bands. The alina, Lockport, Clinton, and Utica formations are all of considerble extent. Both of these streams are practically without forests, lthough slight exception to this statement may be noted on the xtreme headwaters of the Genesee River in Pennsylvania, where here is still a small area of partially cut forest.

It is an interesting circumstance that the geologic formations in which the Genesee and Oneida rivers lie all have a slope to the south or southwest of from 10 to 30 feet per mile. The main trend of the Genesee River is south and north, while the two main branches of Oswego River—Seneca and Oneida—lie east and west. The Mohawk also flows from west to east. On this basis the Portage, Hamilton, Onandaga, Oriskany, Helderberg, and Salina groups lie mostly south of the Seneca and Oneida rivers, while a portion of the Salina, Niagara, Clinton and Medina groups lie mostly to the north. It is interesting, therefore, to speculate as to whether it is possible that considerable water escapes through these formations, finally appearing far to the south, but in the lack of any certain evidence this must be consideerd as merely a speculation.

It may be also noted that for tributaries of the Mohawk River lying to the north, the stratified formations—Utica shales, Trenton group, Calciferous sand rock, etc.—slope toward the stream, and hence may be expected, if there is anything in this view, to deliver more water than that merely due to the rainfall of the catchment as measured on the surface.

On the Upper Mohawk there is some evidence that this is true. The limestones here are open, and at several places streams on the surface sink, to reappear, in one case at any rate, with greatly increased volume several miles farther down. Again, at Howe's cave, in Schoharie County, there is a large stream of water flowing in the cave which, so far as known, does not appear anywhere on the surface.

Moreover, the Muskingum River may be referred to. This stream lies in the unglaciated region in southeastern Ohio, mostly in the horizon of the Conglomerate group of the Carboniferous. The main Muskingum River flows generally from north to south, with its main branches to the east and west, that to the west going a short distance into the Waverly group, which is chiefly sandstone and shale, a subdivision of the Carboniferous. The dip is from west to east. In view of the extremely low run-off of this stream, it seems tolerably evident that there can be no material contribution by percolation through these strata.

As other examples of underground flow, the writer may mention Toyah Creek, in Texas, where a stream of (his recollection is) 40 or 50 cubic feet per second flows from the base of a mountain with no indication as to its source. The well-known streams in Mammoth and Luray caves are doubtless familiar to all. There are also a number of river channels in the West where the water sinks into the porous soils, to reappear at some point lower down; but these are hardly allied to the cases under consideration, because the source is here visible.

A stream at Lausanne, Switzerland, may also be mentioned. In 1872 there was a serious epidemic of typhoid fever at Lausanne, Switzerland, which, on investigation, was found to proceed from a brook irrigating lands about a mile distant from a public well, from which the 800 inhabitants of the village mostly took their water supply. Ten years before, or in 1862, a hole had appeared in the channel of the brook at a certain point, 8 feet deep and 3 feet wide, which disclosed at its bottom a running stream, apparently fed by the brook from a point higher up. The brook itself was led into this hole, with the result that the water all disappeared and in an hour or two streamed out at the public well, showing a connection which had been suspected for years. On refilling the hole the brook returned to its bed.

After the epidemic had ceased in 1872 an investigation was held, the hole was reopened and a large quantity of salt thrown in, its pres-

e in the public well was easily ascertained by a chemical examiion.

This case discloses some points of interest. Here was a considere stream flowing underground which was easily increased from water of the brook, which was on the surface. Again, the flow e was through coarse gravel.

n the literature of canal construction there are a number of cases ed in which large losses of water have taken place either through rse gravel or seamy rocks. Doubtless there are numerous other es, which, however, are not specially important, for it is the iter's intention only to point out, in a general way, reasons why ch losses may sometimes take place.

The outflow from Skaneateles Lake has been cited as showing a ge loss, presumably by percolation through strata, but on reference the original authority it is clear enough that an error has been de in so citing it, because the flow measured was really through 9 les of natural channel and 8 miles of canal, to Montezuma. It may mentioned that the problem to be determined by this measurement s the discharge into Seneca River and it is quite possible that there y have been a deficiency from the west.

Skaneateles Lake lies at an elevation of 867 feet above tide water l a distance of about 9 miles south of the Erie Canal, for which it been used as a feeder since 1844. In 1859 Mr. S. H. Sweet made asurements of the flow to the canal and through the same to Monuma, where the surplus water is discharged into Seneca River, to ich it was found to deliver 125 cubic feet per second. Measureits were also made at the foot of the lake, where the flow amounted 188 cubic feet per second. The loss was 63 cubic feet per second, one-third of the whole. Skaneateles Lake itself lies in the Hamil- formation, and its outlet, on its way to the Erie Canal, flows oss the Onondaga, Oriskany, Helderberg, and Salina formations. e dip is here from north to south, while the stream, which is butary to the Seneca River, the main westerly branch of the vego, flows from south to north, or in the right direction to realize maximum possible leakage, or percolation, through the strata. smuch as no such leakage is mentioned, it may be reasonably conded that none occurred.

Cazenovia Lake and Erieville reservoirs are also mentioned, and siderable loss of water is given, which when analyzed is found be loss of water in the canal, and hence not in any degree attribule to leakage through strata. Cazenovia Lake and Erieville resoirs both lie south of the Erie Canal, and flow across substanlly the same strata as Skaneateles Lake.[a]

Such facts as these, while lacking the proof of a scientific demon-

[a] Ann. Rept. State Engineer and Surveyor for 1882, pp. 403-404.

stration, are still very interesting and indicate that we have yet much to learn of the peculiarities of stream flow. On the whole, while they undoubtedly point to a moderate loss from percolation, so far as the writer can see they do not indicate any great probability of very large loss from this cause. They do emphasize the fact that every catchment area will have its own formula.

By way of showing that the theory of large evaporation on deforested catchment areas is broadly more reasonable than the theory that there is any great loss of water by seepage owing to inclination of the strata, we may consider the Croton record as given by the appended Table No. 3, where it will be noted that the evaporation from this area is substantially the same as that from Muskingum and Genesee rivers; that is to say, it is the evaporation of a deforested area—the area in forest on this catchment does not exceed 10 per cent. In placing it at 10 per cent the writer means the equivalent in actual effect of dense forest. As regards geologic formation this catchment lies almost entirely in granites and gneisses, in which, from their homogeneous character, it is difficult to assume any loss by percolation through strata. There is, however, a small area of metamorphic Hudson formation, consisting of slate, schist, and quartzite, and also a small area of metamorphic Trenton and Calciferous limestones, but it is exceedingly improbable that any rocks which have been subjected to metamorphic changes are in any degree permeable. This watershed must therefore be considered as underlain by an impermeable formation. All of the water falling upon it except that absorbed by evaporation, chemical changes, etc., reappears as run-off in the streams. It may be safely assumed that there are no other losses. Nevertheless, the evaporation of this stream is that tentatively placed upon other deforested areas. Moreover, there is another interesting consideration of which brief note may be taken at this place. In deference to the water supply department of the city of New York, the writer has used in computing the monthly run-off the catchment area of 338.8 square miles. Mr. Vermeule, however, asserts that this area is not the true one. He says the true area above old Croton dam is 353.1 square miles. If we assume this to be true it follows that the average run-off, instead of being 22.8 inches, is over 4 per cent less, or is, roundly, 21.8 inches. This raises the evaporation from 26.6 inches to 27.6 inches. In his report on forests, Mr. Vermeule has placed the evaporation of his second Croton series, which the writer understands him to consider more reliable, at 22.6 inches, a difference of 5 inches from the foregoing figures, which it may be remarked is based upon the latest revision and is presumably more likely to be correct.

The catchment area of Lake Cochituate may be mentioned. According to Mr. FitzGerald, the slopes of the Cochituate catchment *are flat* and sandy, with a surface of mostly modified drift. The *average rainfall* for twenty-nine years, from 1853 to 1891, is 47.1 inches,

the average run-off 20.3 inches, and the evaporation for this period 26.8 inches. This evaporation places it at once in the category of deforested streams. Probably the equivalent of dense forest does not exceed 5 per cent.

The catchment area of Sudbury River has steeper slopes than that of Lake Cochituate and is largely composed of unmodified drift. The rainfall for twenty-six years is 1 inch less than on the Cochituate catchment, and the run-off 2.3 inches larger. The amount of forest does not exceed 6 to 8 per cent. Neshaminy Creek flows from north to south, emptying into the Delaware River not far from Bristol. For several miles its headwaters flow from west to east. Perkiomen Creek flows from north to south, and enters the Schuylkill River about 7 miles above the city of Norristown. Tohickon Creek flows from west nearly due east, although somewhat crooked for a few miles, then flowing in a southwesterly direction it reaches the Delaware River.

The surface of the ground is mostly farm land under a high degree of cultivation. The original forest growth has been almost entirely cut away, and the little remaining timber is found generally on the banks of the creeks, where the hillside is too steep to be cultivated, or on a few patches of bottom land. This growth is mostly composed of hickory, chestnut, oak, and ash. Even this is fast disappearing to supply the ever-increasing demand for railroad ties, fence posts, and rails. The proportion of cultivated lands, woodlands, etc., is as follows: Woodland, about 20 per cent; cultivated land, about 77.5 per cent; roads, 2 per cent, and flats, 0.5 per cent.[a]

On the upper Hudson River, with a catchment above Mechanicville of 4,500 square miles, the average rainfall for the fourteen years from 1888 to 1901, inclusive, was about 44.2 inches, the average run-off 23.3 inches, and the evaporation 20.9 inches. Above Glens Falls this stream lies almost entirely in the pre-Cambrian gneiss, from which it is improbable that there is any loss of water. Its main tributary on the west, Sacandaga, is, by observation, an exceedingly prolific water yielder. To the east, the Battenkill and Hoosic rivers have a different geologic history. The Battenkill flows across the Hudson Vales, the Georgia limestones and shales, finally rising in the metamorphic Hudson and Trenton formations. The Hoosic River has a similar geologic history. The run-off of the Hoosic River is, without doubt, considerably less than that of the main Hudson. The average precipitation in western Massachusetts from 1887 to 1895, inclusive, was 38.98 inches, as against 43.29 inches in the northern plateau from 1889 to 1895, inclusive, a difference of 4.31 inches. Should such difference continue, the run-off of Hoosic River might be expected to be, on an average, about 20 inches. Moreover, the Hudson River above Glens Falls (catchment about 2,800 squares miles) is still largely in forest—probably about 85 per cent—but on

[a] Codman, John E., Observations on rainfall and stream flow in eastern Pennsylvania: Proc. Engrs. Club of Phila., Vol. XIV, No. 2, July-Sept., 1897.

the catchments of Wood Creek, Battenkill, and Hoosic rivers the proportion of forest is very much less—as an offhand estimate, the writer would say perhaps 20 to 30 per cent. The run-off of Schroon River, which is perhaps 70 per cent of an equivalent to fairly dense forest, is for four years 26.84 inches. There is, however, some doubt whether this record is entirely reliable, and for the present it is not intended to more than merely call attention to the general proposition that this stream, which issues from an impermeable watershed with 70 per cent of its catchment in forest, has a rather large run-off. The whole catchment area of the Upper Hudson of about 4,500 square miles, will probably not exceed 50 to 60 per cent of forest.

The following are the catchment areas of the several streams here considered: Hoosic, 711 square miles; Battenkill, 438 square miles; Sacundaga, 1,057 square miles, and Schroon River, 570 square miles.

The Pequannock River may also be referred to. This stream is characterized by sharp slopes throughout its whole extent. Its headwaters are at an elevation of about 1,500 feet, while the mouth is only 170 feet above tide. The catchment is about 14 to 16 miles long by 4 to 7 miles wide. Mr. Vermeule states that its headwaters lie in the pre-Cambrian highlands. The sharp slopes, combined with small catchment area, undoubtedly account for the relatively large run-off of this stream. There is also an uncertainty of 1 or 2 inches in the rainfall record. The catchment is judged by the writer to be 70 per cent forest.

In riding over the Pequannock catchment several times the writer was much struck by the fact that aside from the main valleys there are no gulleys throughout this area. The record shows that precipitation is frequently very heavy, but it has been thus far without effect. The indications appear to be that the rainfall, however intense it may be, sinks almost entirely into the ground, and without doubt this peculiarity has its effect on the run-off.

It may be pointed out that the geology of Muskingum and Genesee rivers is substantially the same, while the geology of Croton River and that of Lake Cochituate are entirely different. Nevertheless, when analyzed by aid of the diagrams (figs. 12–16, inclusive), these streams are seen to all have substantially the same evaporation and run-off, although the rainfall on Croton River and Lake Cochituate is different from that of Muskingum and Genesee rivers. Hudson River, however, which has much the same geology as Croton River and Lake Cochituate, has still a very different run-off and evaporation. Oswego River, which lies in a different formation from Genesee River, has still nearly the same evaporation.[a]

These several facts favor the view that deforestation is the real cause of the smaller run-off of Muskingum, Genesee, and Croton rivers and Lake Cochituate.

[a] The evaporation of Oswego River is, in fact, a little greater, due to the existence of large *marsh* areas on Oswego River.

EFFECTS OF FORESTS.

DO FORESTS INCREASE RAINFALL?

The evidence on this point is conflicting. The variation of the observed from the true rainfall being so great, as has just been shown, he answer to this question must be regarded as very uncertain. It as been discussed by Professor Abbe and Dr. Hough.[a] The following summation by Dr. Hough, although made 26 years ago, may be ccepted as expressing the fact at the present day.

The reciprocal influences that operate between woodlands and climate appear o indicate a close relation between them. It is observed that certain consequences ollow the clearing off of forests, which can scarcely be otherwise regarded than s a direct effect, such as the diminution of rivers and the drying up of streams nd springs. Other effects, scarcely less certain, are seen in the occurrence of estructive floods, and of unseasonable and prolonged droughts, with other vicisitudes of climate which it is alleged did not occur when the country was covered ith forests. These appear to have been brought about by their removal, and ight, in a great degree, be alleviated by the restoration of woodlands to a degree onsistent with our best agricultural interests.

On the other hand, there are many facts tending to show that the presence or bsence and the character of forests are the effect of climate, and that their cultivation generally, or the planting of particular species, is closely dependent upon t. These conditions of climate should be understood before forest cultivation is ttempted. It is also to be noticed that differences of opinion have been expressed mong men of science as to the extent of influence that forests exert upon the limate, and it is quite probable that the advocates of extreme theories may have red on both sides. But where principles depend upon facts that may be settled y observation, there should be no differences of opinion; and as there is no fact n this subject that may not be verified or disproved, the existence of such ifferences only shows the want of accepted evidence derived from trustworthy ecords.

The interested reader is referred to Dr. Hough's report, which may be easily obtained, for an extended discussion on this point.

EFFECTS OF FORESTS ON RUN-OFF.

The extent of forestation has probably a considerable effect on the run-off of streams. With similar rainfalls, two streams, one in a region having dense primeval forests, the other in a region wholly or partially deforested, will show different run-off. The one with the dense forests will show larger run-off than the stream in the deforested area. In some parts of the State of New York these differences may amount to as much as 5 or 6 inches in depth over the entire catchment area. Yet it must be said that this proposition is, for the present, tentative in its character.

The writer is particular to specify dense forests, because a good deal of discussion has clustered around this point. Of such forests,

[a] Report upon forestry, by Franklin B. Hough, U. S. Department of Agriculture (1877).

the most effective are those composed of spruce, pine, and other evergreen trees. Where the forest is more or less open to wind and sunshine, its effect, while considerable, is still much less marked than that of dense evergeen forests where the sun seldom penetrates and the wind effect, even in a gale, is only slight. On a catchment area where there are only scattered patches of forest, the effect is practically the same as on a deforested area. The same proposition is generally true on a catchment with young trees. What is wanted for the maximum effect is a mature evergreen forest.

This proposition, however, though definitely stated here, has been nevertheless the subject of considerable discussion, and owing to its complex nature, it is improbable that a final conclusion concerning it will very soon be reached. The writer has discussed this subject in various papers, which may be referred to for details that are mostly omitted here.[a]

WHY THE REMOVAL OF FORESTS AFFECTS STREAM FLOW.

Whatever question there may be as to the influence of forests on rainfall, there is, in the opinion of the writer, none as to such influence on stream flow. Yet this proposition has also been discussed pro and con and is likely to give rise to further discussion, and the conclusion will, therefore, for the present be considered tentative in its character.

It seems to the writer that the removal of forests decreases stream flow by allowing freer circulation of the air and by causing higher temperature and lower humidity in summer and so producing greater evaporation from water surfaces, as well as from the ground.

---

[a] The following reports and papers are cited:

1. Three reports on Genesee River storage surveys: Appendixes to Ann. Repts. State Engineer and Surveyor for 1893, 1894, and 1896.

2. Two reports on Upper Hudson storage surveys: Appendixes to Ann. Repts. State Engineer and Surveyor for 1895 and 1896.

3. Water supply of the western division of the Erie Canal: Ann. Rept. State Engineer and Surveyor for 1896.

4. The economics of the Hudson River: lecture before the engineering classes of Rensselaer Polytechnic Institute, Feb. 24, 1897.

5. Stream flow in relation to forests: Proc. Am. Forestry Association, Vol. XII, 1897; also reprint in Ann. Rept. Fisheries, Game and Forest Commission (1896), published in 1898. Reprint, 1898.

6. Natural and artificial forest reservoirs of the State of New York: Third Ann. Rept. Fisheries, Game, and Forest Commission (1897), published in 1899. Reprint, 1899.

7. Water Resources of the State of New York, Parts I and II: Water-Supply and Irrigation Papers U. S. Geol. Survey, Nos. 24 and 25, 1899.

8. On the application of the principles of forestry and water storage to the mill streams of the State of New York: Proc. Twenty-second Ann. meeting of Pulp and Paper Association. (1899.)

9. Indian River dam, by Geo. W. Rafter, Wallace Greenalch, and Robert E. Horton: Engineering News, May 18, 1899. Reprint, 1899.

10. Data of stream flow in relation to forests: lecture before engineering classes of Cornell University, April 14, 1899: Trans. Association of Civil Engineers of Cornell University, Vol. VII, 1899. Reprint, 1899.

11. A report on a water supply from the Adirondack Mountains for the city of New York: Appendix E of an inquiry into the conditions relating to the water supply in the city of New York by the Merchants' Association, 1900.

12. Report to the Board of Engineers on deep waterways, on the water supply of enlarged canals through the State of New York; Appendix 16, pp. 571-950. (1901.)

That the removal of forests renders stream flow less equal throughout the year and so causes floods and periods of dryness in rivers seems to be beyond reasonable question, for the forest litter and root masses serve as storage reservoirs, tending to equalize the flow of streams.

Space will not be taken to discuss these propositions, because very little can be added to previous discussions. The reader is referred to the Bulletin No. 7, of the Forestry Division of the Department of Agriculture on Forest Influences, as well as to Dr. Hough's report on Forests, for fairly complete discussions.

FORESTATION OF THE CROTON CATCHMENT AREA.

In a paper[a] read before the American Forestry Association in 1901, Mr. Vermeule proposes the question whether the forestation of the catchment area of the Croton water supply is advisable. In considering this question it may be pointed out that if the Croton watershed were forested, there is no probability of reaping the full benefit under from 75 to 150 years. On this point the following statement by Mr. B. E. Fernow, director of the New York State College of Forestry, at Cornell University, is pertinent:[b]

> The one thing in which the forestry business differs from all other business is the long-time element, for it takes 100 years and more to grow trees fit for the use of the engineer, the builder, and the architect; hence the dollar spent now in its first start must come back, with compound interest, 100 years hence.

For the sake of the argument, we will assume that on this watershed in 120 years the full effect of forestation would be realized. This would give, as an average, an increase of from 4 to 6 inches in run-off. For the purposes of this discussion we may assume it at 5 inches.

In order to forest the watershed it would be necessary to acquire the entire area, which, so far as the writer can ascertain, could hardly be done for less than $100 per acre. Probably the price would be much greater than this, but to avoid an overestimate it may be fixed at $100 per acre. At this rate the catchment area of 339 square miles would cost $21,696,000. The planting out of trees could hardly cost less than $20 per acre additional, but in order to make the estimate as reasonable as possible we will take it at $10 per acre, which makes an additional sum of $2,169,900, or a total of $23,865,900.

If we assume the annual interest at 3 per cent, and place this sum at compound interest for 120 years, we have at the end of that time the sum of $779,510,000. The present safe yield of the Croton watershed, with all available storage, is about 280,000,000 gallons per day. We would pay, therefore, this large sum for, perhaps, 75,000,000 gallons additional per day at the end of 120 years. It is true, there

[a] New Jersey forests and their relation to water supply, by C. C. Vermeule: The Engineering Record, Vol. XLII, No. 1 (July, 1901).

[b] The forester an engineer, by B. E. Fernow: Jour. Western Soc. Engrs., Vol. VI, No. 5 (Oct., 1901).

would be some increase in water supply after about 30 years, and the supply might be expected to go on increasing until the average increase of yield was attained in 120 years. But the increase in water supply would not be at all commensurate with the increase of capitalization. It is very evident that an expenditure of this sum of money would procure a far greater quantity of water from other sources. Hence it does not seem expedient to suggest the forestation of the Croton catchment area.

Another objection to the forestation of the Croton watershed as a remedy for the water difficulties of New York City may be found in the fact that a considerably increased water supply is wanted at once; it is entirely out of the question to wait 120 years for such increased supply.

As a broad proposition, however, catchment areas from which municipal water supplies are drawn should be in forests, and undoubtedly as time goes on this condition will be more and more attained. Already various European and American municipalities have recognized the advisability of owning the catchments from which their municipal water supplies are drawn.

DETAILS CONCERNING TABLES AND DIAGRAMS.

TOPOGRAPHIC RELATIONS OF CATCHMENT AREAS OF STREAMS TABULATED.

The following gives an outline of the topography of the several catchment areas included in the tables.

The headwaters of Muskingum River lie at an elevation of about 1,100 feet, and it flows into the Ohio River, near Marietta, at an elevation of about 500 feet. The Muskingum River proper has a length of 109 miles, with its main tributaries, the Walhonding and the Tuscarawas, having an additional length of about 100 miles, thus giving the basin a length of 200 miles. From the head of the Tuscarawas to the junction of the two main tributaries there is a fall of about 2 feet per mile, and from this point to the mouth of the main Muskingum the descent is about 1.5 feet per mile. On the Walhonding the descent is more rapid. At its headwaters, near Mansfield, the stream is from 400 to 450 feet above what it is at its junction with the Tuscarawas.

The Genesee River rises in Potter County, Pa., and flows in a northerly direction across the State of New York, emptying into Lake Ontario at Rochester, having a total length of about 115 miles. Its headwaters are at an elevation of over 2,000 feet, while Lake Ontario lies at a mean elevation of 247 feet. This stream is specially characterized by two sets of falls. The three falls at Portage have an aggregate of about 270 feet, while at Rochester the river falls 263 feet, also in three falls, with some intervening rapids. This stream flows *for several* miles at Rochester and Portage over bare rocks.

he Croton River flows into the Hudson at Croton Landing at an ation of practically tide water. Its extreme headwaters in chess County are at an elevation of about 700 feet above tide. Its th is about 35 miles.

ake Cochituate is in a generally flat area at an elevation of about feet above tidewater. A small area in the south portion rises to levation of 300 feet. The greatest extent of this area is from heast to southwest, about 9½ miles, with an average width of ut 2 miles. In the northern part it is narrower than this and in southern somewhat greater.

udbury River catchment area lies immediately to the west of the e Cochituate catchment. The elevations vary from about 200 feet ve tide to from 500 to 600 feet. Its length from north to south is ut 10 miles, and from east to west about 8 miles. Owing to a ber of hills throughout the area the slopes are much steeper than the Cochituate catchment. Sudbury catchment lies about 25 s to the west of Boston.

ystic Lake is practically at sea level, with considerable hills in a tion of the catchment area. The slopes are steep, but not quite as p as Sudbury.

eshaminy Creek flows into the Delaware River at an elevation of n 10 to 20 feet above tide water. Its headwaters are at an elevation bout 300 feet. Its extreme length from north to south is from 40 5 miles.

erkiomen Creek flows into the Schuylkill at an elevation of about eet above tide level. The headwaters are at an elevation of 550 . The length of the basin from north to south is about 30 miles.

ohickon Creek flows into the Delaware River at an elevation of ut 70 feet above tide. Its extreme headwaters are at an elevation 25 feet. Its length, from east to west, is about 25 miles.

udson River, at Mechanicville, is about 60 feet above tide, while ts extreme headwaters it is about 3,400 feet above tide level. catchment area above Glens Falls is from 40 to 50 miles from east est and from 60 to 65 miles from north to south. Below Glens ls the catchment extends well into southern Vermont and Massa-setts. The length of the stream above Mechanicville is from 120 25 miles.

equannock River flows into the Passaic near Pompton, at an eleva- of 170 feet above tide. The main facts of the topography of this am have been given in the chapter on "The relation of geology to run-off of streams."

he Connecticut River flows into Long Island Sound at tide water, rises in the northern part of New Hampshire. Its extreme head-ers issue from an elevation of 2,000 to 3,000 feet above tide level. ength is about 375 miles. The topography of this catchment is y and, in the northern part, mountainous.

CLASSIFICATION OF STREAMS.

In Table No. 13 we have the mean rainfall, run-off, and evaporation of the storage, growing, and replenishing periods of the streams for which individual figures are given in Tables Nos. 1 to 12, inclusive. This table shows what may be termed the family resemblance between streams. For instance, for the Muskingum and Genesee rivers the mean rainfall of the storage period is about 19 inches, with a run-off of about 10 inches and an evaporation of about 9 inches. For the growing period the mean rainfall of each of these two streams is about 12 inches, with run-off 1.7 inches and evaporation 10 inches. For the replenishing period the mean rainfall of each is about 9 inches, with run-off about 2 inches and evaporation 7.5 inches. The total rainfall of the whole year is 40 inches for each stream—run-off 13.5 inches and evaporation 26.5 inches.

The Croton River has a much higher rainfall. Twenty-four inches in the storage period produces 17 inches of run-off, with an evaporation of 7 inches. From 13.6 inches of rain in the summer we have 2.6 inches of run-off, with 11 inches of evaporation. The rainfall for the year is 49.4 inches, or, say, 9 inches more than for Muskingum and Genesee rivers. The run-off is also about 9 inches in excess of that of these two streams. The evaporation is, however, the same, pointing very strongly to a similar cause.

On Lake Cochituate catchment 23.1 inches rainfall in the storage period produces on an average but 14.9 inches of run-off, with 8.2 inches of evaporation. The rainfall of the growing period is the same as that of the Muskingum and Genesee rivers, yielding, however, 2.1 inches run-off and 9.5 inches evaporation. For the replenishing period, 12.4 inches rainfall yields 3.3 inches run-off, with 9.1 inches evaporation. The totals for the year are, rainfall, 47.1 inches; run-off, 20.3 inches, and evaporation, 26.8 inches. Aside from difference in catchment areas, the total evaporation of both Croton River and Lake Cochituate is substantially the same as that of Muskingum and Genesee rivers. The excess rainfall of Lake Cochituate over Muskingum and Genesee rivers is about the same as the excess evaporation; that is to say, 7.5 inches. As regards evaporation, Lake Cochituate may therefore class with the Muskingum, Genesee, and Croton rivers.

For Sudbury River, Mystic Lake, Neshaminy and Perkiomen creeks, somewhat different conditions prevail. The yearly evaporation is here about 24 inches, and, with the exception of Mystic Lake, the run-off is about 23 inches. On Mystic Lake catchment the rainfall is enough smaller to fully account for the difference in run-off. Broadly, these four streams may be considered as making a second class.

Tohickon Creek has a total annual mean rainfall of 50 inches, from whence it results that the mean yearly run-off is 28.4 inches and the

evaporation 21.7 inches. This stream varies so much, from what the general principles indicate, that the writer doubts somewhat the correctness of the record. He considers it quite possible that it may be 10 per cent to 20 per cent in error. Reasons for this view are given in the chapter on "Negative evaporation." The writer recognizes, however, that in view of the uncertainty of gagings, etc., the mere fact of a stream not squaring with preconceived views ought not to condemn its record. There must be valid reasons for rejecting the particular record.

The Hudson River shows apparently the effect of an impermeable catchment, combined with a large forest area. It has a mean annual rainfall of 44.2 inches, yielding 23.3 inches run-off, with 20.9 inches evaporation. For the storage period 20.6 inches rainfall yields 16.1 inches run-off, with 4.5 inches evaporation. For the growing period 12.7 inches rainfall yields 3.5 inches run-off, with 9.3 inches evaporation. For the replenishing period 10.9 inches rainfall yields 3.7 inches run-off and 7.1 inches evaporation. This stream, from general similarity, may properly classify with the Connecticut.

For the Pequannock River explanations have already been given, which apply generally. For the present it tentatively stands in a class by itself.

The classification here given is experimental merely, and is subject to modification with the gathering of more complete data.

DESCRIPTION OF TABLES NOS. 1 TO 12.

Table No. 1 gives the rainfall, run-off, and evaporation of the storage, growing, and replenishing periods, as well as the total of these three items, on the Muskingum River, for the years 1888–1895, inclusive. The minimum year was 1895, the total run-off being 4.90 inches. The maximum occurred in 1890, with a total run-off of 26.84 inches. The mean run-off for the entire period is 13.1 inches.

Table No. 2 gives the same facts for the Genesee River for the years 1890–1898, inclusive. In this table, for the years 1890–1892, the record of Oatka Creek, which was gaged by the writer, has been used. For a portion of 1893, the results are computed. The dam at Mount Morris, at which gagings were taken, was carried away by a flood early in 1897, and for the years 1897 and 1898 the gaging record has been deduced by comparison of the rainfalls with those at Rochester, where gagings are kept by the city engineer. The results, aside from those for the years 1894–1896, must be considered somewhat approximate, although probably within 10 per cent of the truth. The mean evaporation for the years 1894–1896 was 27.21 inches.

Table No. 3 exhibits the rainfall, run-off, and evaporation of the storage, growing, and replenishing periods for Croton River, from 1868–1899, inclusive, a period of thirty-two years. This record has

been revised as per experiments at Cornell University, described by John R. Freeman, member American Society Civil Engineers, in his report to the comptroller in 1900. As shown by Mr. Freeman, the rainfall record from 1868–1876, inclusive, is not very reliable, and accordingly two sets of means are given. The mean rainfall from 1868–1876, inclusive, was 45 inches, the mean run-off 23.37 inches, and the mean evaporation 21.63 inches. For the second period the rainfall from 1877–1899, inclusive, has been so rationally treated by Mr. Freeman as to leave nothing to be desired. The means for this second period are: rainfall, 49.33 inches; run-off, 22.81 inches, and evaporation, 26.52 inches. A comparison of these two sets of means shows how dangerous it is to draw final conclusions from data about which there is considerable doubt. The rainfall differs by 4.33 inches and the evaporation by 4.89 inches, or from 20 per cent to 25 per cent.

In preparing this table the figures of table No. 26 of Mr. Freeman's report have been used. This table is in million gallons per 24-hour day, and has been reduced to inches per month on the catchment area of 338.8 square miles. The following gives the water surfaces exposed to evaporation at different periods:

	Per cent.
5.8 square miles, 1868–1873,	= 1.73
6.2 square miles, 1873–October, 1878,	= 1.83
6.9 square miles, 1878–1891,	= 2.03
8.4 square miles, 1891–1893,	= 2.48
9.5 square miles, 1893–1895,	= 2.82
11.0 square miles, 1895–1897,	= 3.28
12.0 square miles, 1897–1900,	= 3.56

It may at first thought be imagined that these large water sufaces exposed to evaporation have considerably increased the ground evaporation over the entire catchment. When, however, one considers that it is only the difference between what a water-surface evaporation and what a ground-surface evaporation would be, the difference is seen to be not very much. For instance, assuming the water-surface evaporation at 36 inches per year and the ground-surface evaporation at 27 inches per year, the difference becomes 9 inches. With 12 square miles of water surface in 1900, giving 3.56 per cent of the whole, the excess of water-surface evaporation over ground-surface evaporation is 0.32 of an inch, a quantity which is so far within the limit of possible error in other directions as to be negligible. At the most, taking the assumed catchment area at 338.8 square miles, it would only reduce the evaporation from 26.5 inches to 26.2 inches.

The minimum year in this table is seen to be 1880, when only 13.71 inches ran off. In 1883 the run-off was also very low, being only 13.74 inches.

Table No. 4 exhibits a similar set of facts for Lake Cochituate from *1863–1900*, inclusive. Two sets of means are also given in this case,

one from 1896–1900, a period of 5 years, and the other from 1863–1900, a period of 38 years. There is very little difference between these two sets of means. The minimum year is seen to have been 1883, when there was only 10.09 inches of run-off.

Table No. 5 gives the same data for Sudbury River from 1875–1900, inclusive, a period of 26 years. Two sets of means, one for the five years from 1896–1900, inclusive, and the other for the entire period of 26 years, are also given in this case. The catchment area of this stream is hilly, and considerable variation in rainfall may be expected to take place. Originally only one rain gage was exposed, but latterly there are several, and the rainfalls as given in the table are the means of these. In 1883, which was the year of minimum run-off, only 11.40 inches appeared in the stream, out of a total precipitation of 31.52 inches.

According to the Sixth Annual Report of the Metropolitan Water Board, rainfall observations for Sudbury catchment were taken as follows: January, 1875, to April, 1876, Lake Cochituate only; April to June, 1876, Lake Cochituate, Westborough, and Hopkinton; June to December, 1876, Lake Cochituate, Southborough, Marlborough, Westborough, and Hopkinton; December, 1876, to January, 1883, Framingham, Southborough, Westborough, Marlborough, and Hopkinton; January, 1883, to January, 1884, Framingham and Southborough; January, 1884, to January, 1890, Framingham and Westborough; January, 1890, to May, 1898, Framingham and Ashland dam; June, 1898, to December, 1900, Framingham, Ashland dam, Cordaville, and Sudbury dam.

The catchment area of Sudbury River, from 1875–1878, inclusive, was 77.764 square miles; in 1879 and 1890 it was 78.238 square miles, and from 1881–1900, inclusive, 75.2 square miles.

On Sudbury catchment water surfaces were 1.9 per cent of the whole from 1875–1878, inclusive; they were 3 per cent in 1879, 3.4 per cent in 1885, 3.9 per cent in 1894, and 6.5 per cent in 1898. The catchment also contains extensive areas of swamp land, which, although covered with water at times, are not included in the above percentages of the water surfaces.

Table No. 6 gives the rainfall, run-off, and evaporation of the storage, growing, and replenishing periods for Mystic Lake catchment, from 1878–1895, inclusive, a period of 18 years. The minimum year, with a total run-off of 9.44 inches, occurred in 1883. Since it is the run-off of the minimum year which determines the value of a stream for water supply, this figure shows that this stream is not, on the whole, as good a water yielder as Lake Cochituate and Sudbury catchments.

Table No. 7 gives the rainfall, run-off, and evaporation of the storage, growing, and replenishing periods for Neshaminy Creek for the

years 1884–1899, inclusive, a period of 16 years. The minimum yea was 1895, when, with a rainfall of 38.59 inches, 18.15 inches ran off Neshaminy Creek may be taken as a deforested area.

Table No. 8 gives for Perkiomen Creek the rainfall, run-off, an evaporation of the storage, growing, and replenishing periods for th 16 years from 1884–1899, inclusive. The minimum year was 189 when, with 40.35 inches rainfall, the run-off was 17.58 inches. Th writer's recollection is that in riding through this area some time ag the forest is mostly scattered and is probably equivalent in effect t not more than 8 per cent to 10 per cent of dense forest. If he is wron in this, he will be glad to be set right.

Table No. 9 gives for Tohickon Creek the rainfall, run-off, an evaporation of the storage, growing, and replenishing periods fro 1884–1898, inclusive, a period of 15 years. The year of minimum ru off was 1896, when 48.03 inches of rainfall yielded 19.73 inches of ru off. The rainfall of this catchment is considerably higher than th of the two contiguous streams, from whence it results that the ru offs are also larger.

Table No. 10 gives the rainfall, run-off, and evaporation of the sto age, growing, and replenishing periods for the Hudson River area f a period of 14 years, from 1888–1901, inclusive. The minimum ye was 1895, when 36.67 inches of rainfall yielded 17.46 inches as run-o in the stream.

Table No. 11 gives the rainfall, run-off, and evaporation of the sto age, growing, and replenishing periods of the Pequannock River cate ments for 9 years, from 1891–1899, inclusive. The minimum year w 1895, when, with 37.92 inches of rainfall, 21.11 inches appeared run-off. The rainfall record for this catchment area is not entire satisfactory and further study may modify it somewhat.

Table No. 12 gives the rainfall, run-off, and evaporation of the st age, growing, and replenishing periods for the Connecticut River Hartford for a period of 14 years, from 1872–1885, inclusive. T minimum year was 1883, when, with 32.55 inches of rainfall, 12. inches ran off. The record, however, of the year 1883 is that of H yoke, Mass., the years 1882 and 1883 not being given in Mr. Babb paper, from which these data are otherwise taken. For these yea the rainfall has been computed and is, of course, approximate.

Moreover, the record of Connecticut River as a whole can not deemed very satisfactory, either as regards the rainfall or the run-o The run-off is probably anywhere from 5 per cent to 20 per cent excess and a considerably larger number of stations should be av aged to give safe rainfall. The record at Holyoke from 1880–18 inclusive, is considered much more satisfactory, but unfortunat this record is not accompanied by the rainfall, and thus far the wri has not had an opportunity to obtain these.

DESCRIPTION OF DIAGRAMS

We may now consider a few of the large number of diagrams which have been prepared.

Fig. 1 shows, for the Upper Hudson, precipitation, evaporation, run-off, and mean annual temperature for the years 1888–1890, inclusive, plotted in the natural order.

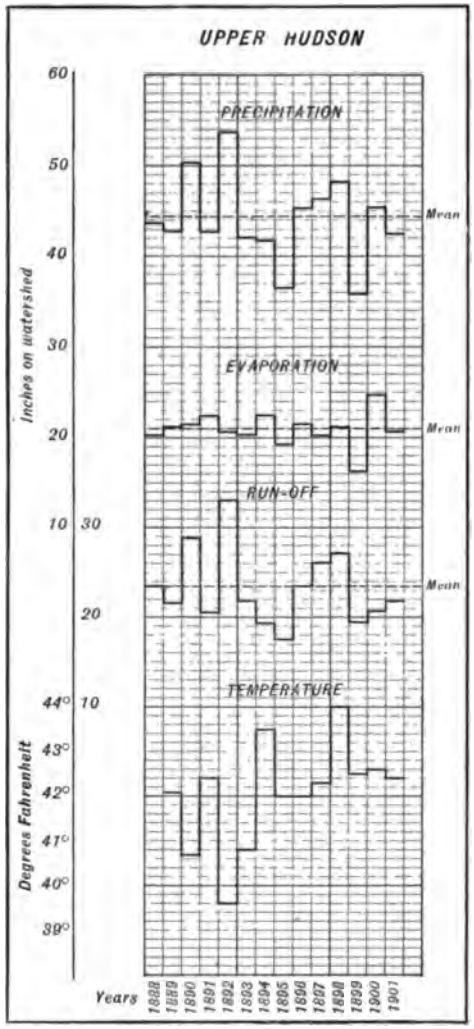


Diagram showing relation between precipitation, evaporation, run-off and temperature on the Upper Hudson River.

Fig. 2 shows, for the same area, evaporation and mean annua perature, plotted in the order of the evaporation.

Fig. 3 shows, for the Upper Genesee, precipitation, evapor run-off, and mean annual temperature, plotted in the order precipitation.

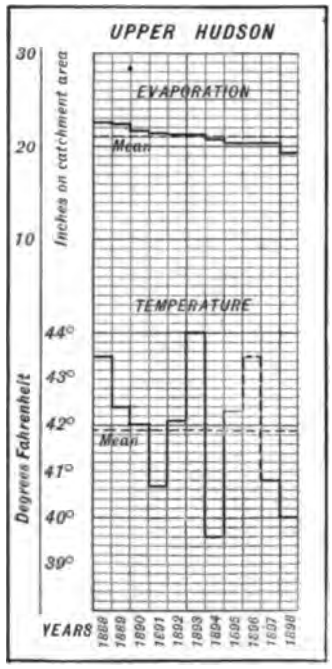


FIG. 2.—Diagram showing the relation between evaporation and temperature on the Upper Hudson River, the years being arranged according to the amount of evaporation.

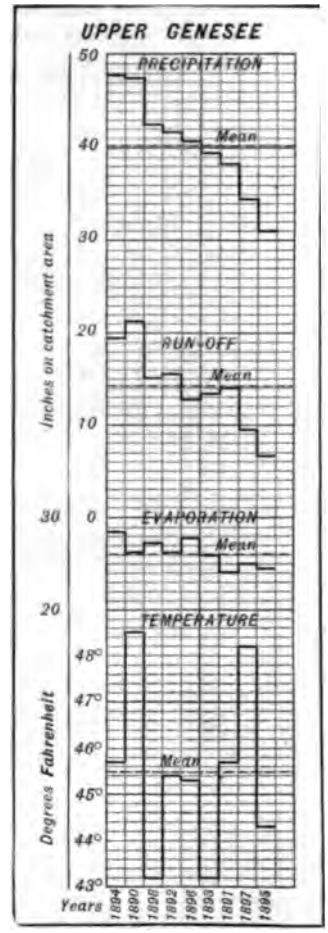
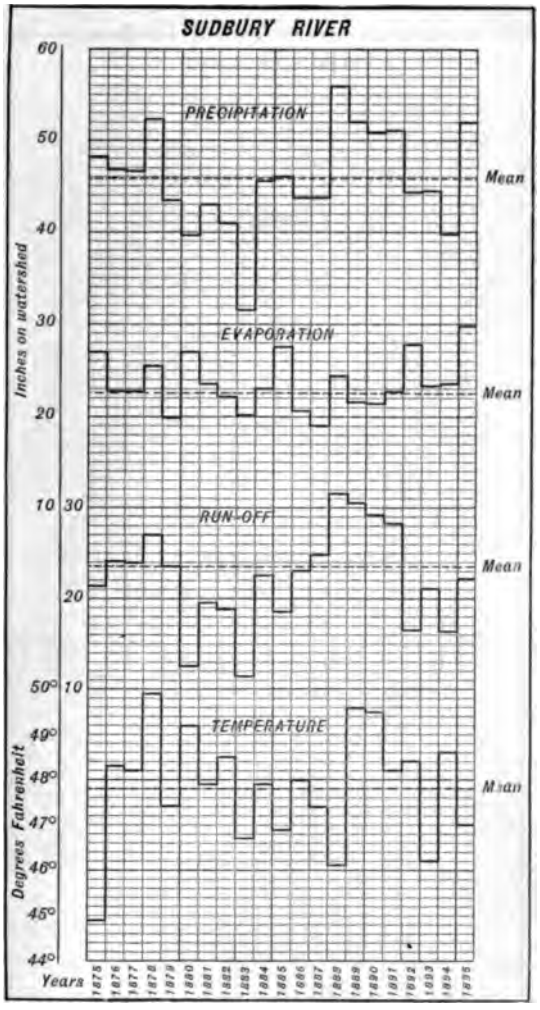


FIG. 3.—Diagram showing the relation between precipitation, run-off, evaporation, and temperature on the Upper Genesee River, the years being arranged in order of dryness.

Fig. 4 shows, for Sudbury River, precipitation, evaporation, run-off, d mean annual temperature, plotted in the natural order.



-Diagram showing the relation between precipitation, evaporation, run-off, and temperature on the Sudbury River, Massachusetts.

On fig. 5 we have, for the same stream, precipitation, evaporati run-off, and mean annual temperature, plotted in the order of precipitation.

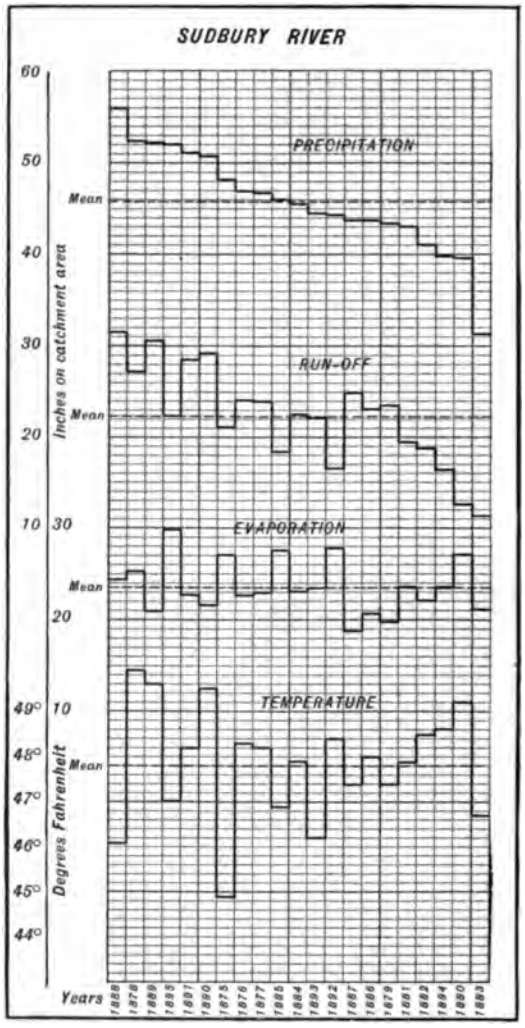


FIG. 5.—Diagram showing relation between precipitation, evaporation, run-off, and tem ture on the Sudbury River, Massachusetts, the years being arranged in order of dryne

On fig. 6 we have, also for Sudbury River, evaporation and mean annual temperature, plotted in the order of the evaporation.

Fig. 7 shows, for the Muskingum River, precipitation, evaporation, run-off, and mean annual temperature, plotted in the order of the precipitation.

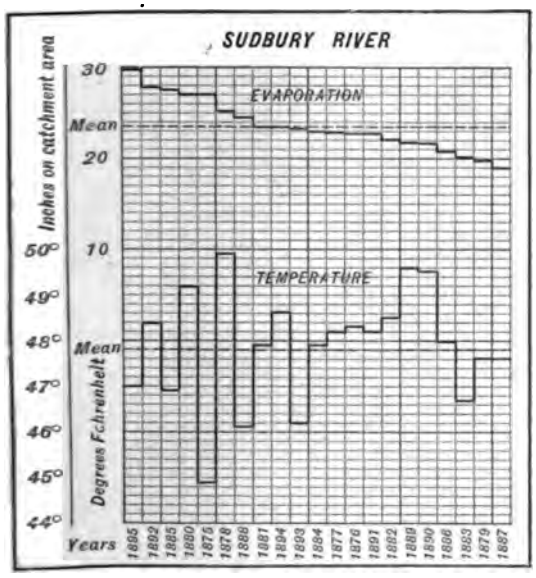


Fig. 6.—Diagram showing the relation between evaporation and temperature on the Sudbury River, the years being arranged according to the amount of evaporation.

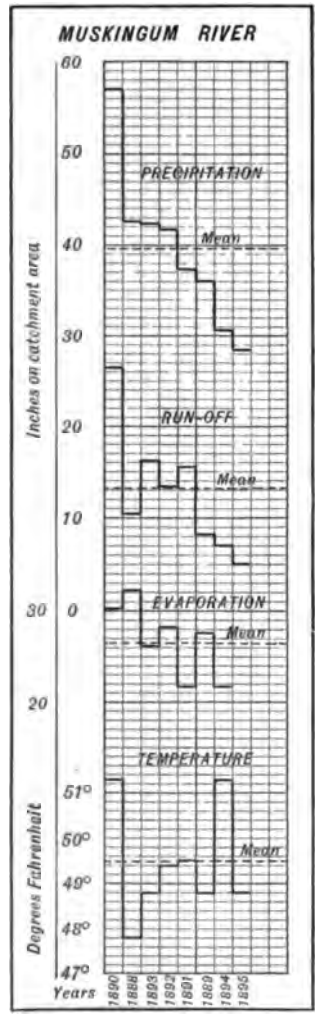


Fig. 7.—Diagram showing the relation between the precipitation, run-off, evaporation, and temperature on the Muskingum River, Ohio, the years being arranged in order of dryness.

Fig. 8 shows, for Lake Cochituate, precipitation, evaporation run-off, and mean annual temperature, plotted in the order of the precipitation.

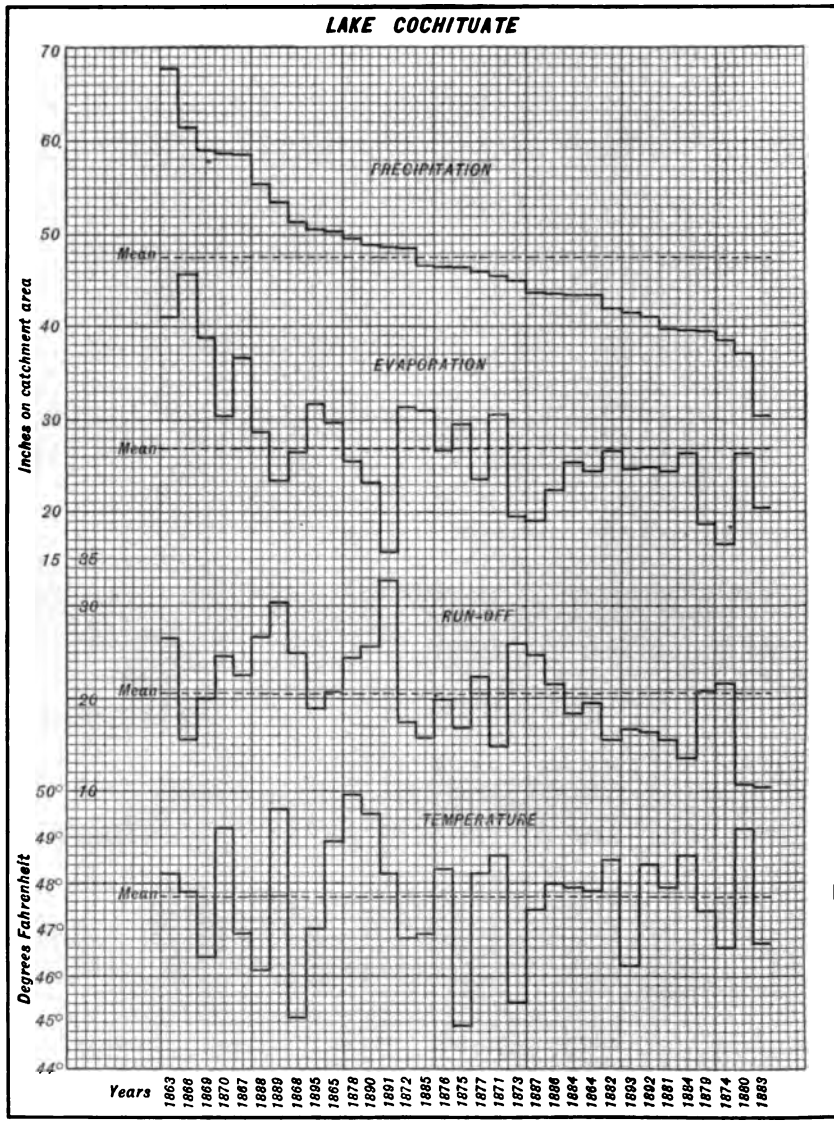


FIG. 8.—Diagram showing the relation between the precipitation, evaporation, run-off, and temperature in the Lake Cochituate Basin, the years being arranged in order of dryness.

Fig. 9 shows, for Lake Cochituate, evaporation and mean annual temperature, plotted in the order of the evaporation.

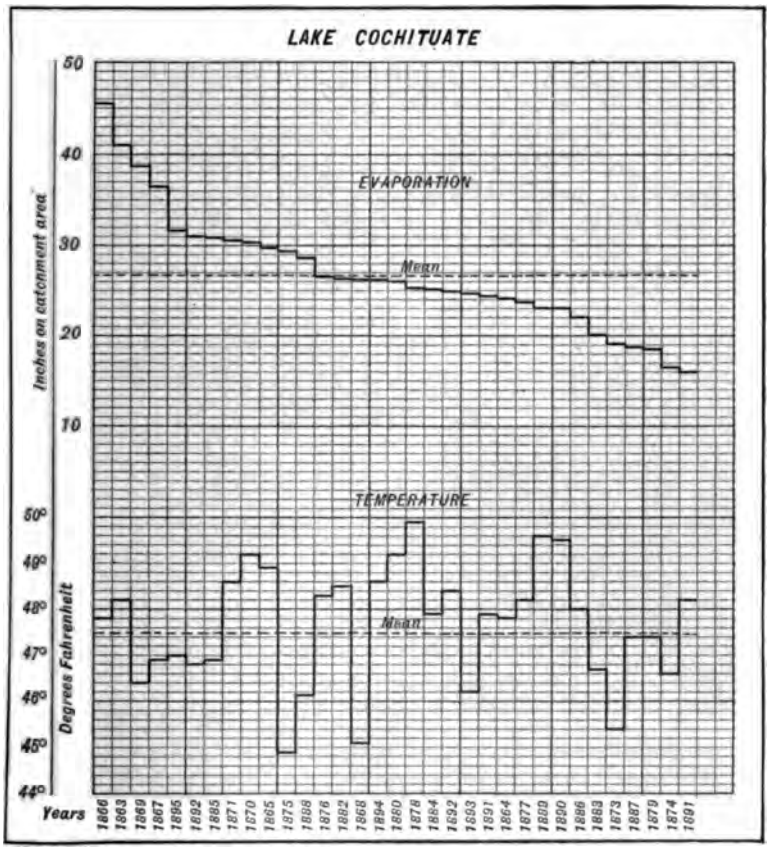


FIG. 9.—**Diagram** showing the relation between evaporation and temperature in the Lake Cochituate Basin, the years being arranged according to the amount of evaporation.

On fig. 10 the relation between precipitation and run-off, for the Upper Hudson, has been expressed by the formula $P^2=84.5\ R$. These diagrams (figs. 1 to 10) all show, together with many others not here published, that there is no definite relation between evaporation and mean annual temperature.

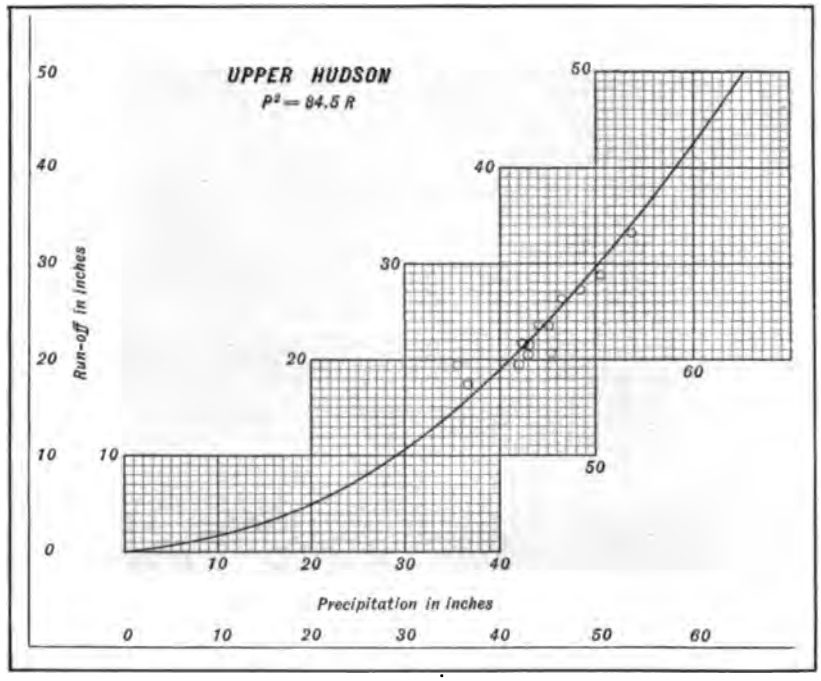


FIG. 10. Diagram showing the relation between the precipitation and run-off in inches on the Upper Hudson River.

EXPONENTIAL FORMULA.

On fig. 11 this relation is expressed by an exponential formula, after the manner proposed by Mr. FitzGerald in his paper, "Flow of water in 48-inch pipes."[a] Such a curve has the advantage that it is the best approximation possible to obtain from the given data. It will be noticed that it differs slightly from the curve of fig. 10. At 30 inches rainfall this difference amounts to about 1.3 inches of run-off.

While on the subject of exponential formulas it may be remarked that their chief advantage lies in the possibility of taking any set of data and deducing the curve which best suits the conditions.

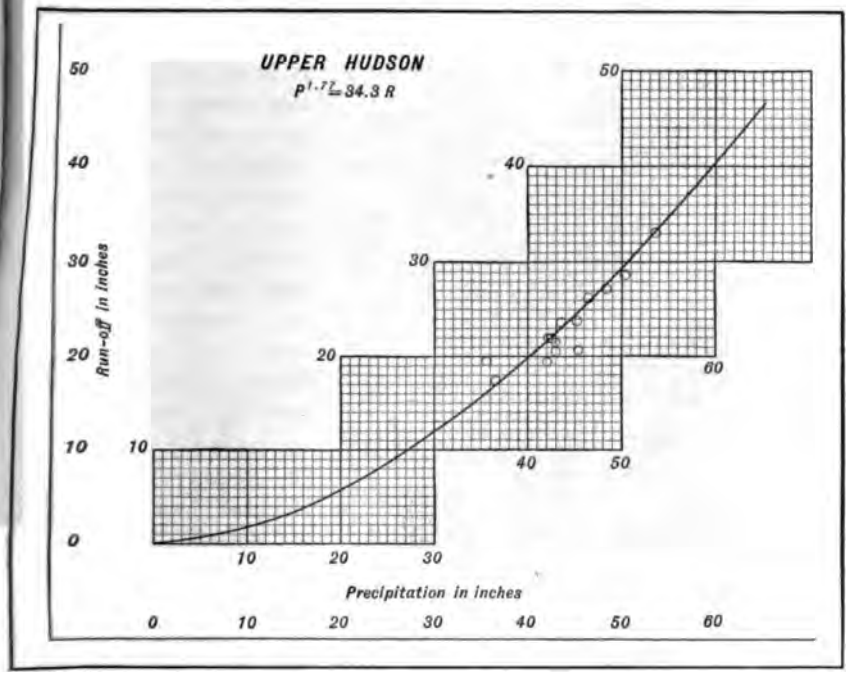


FIG. 11.—Diagram showing the relation between the precipitation and run-off in inches on the Upper Hudson River, expressed by exponential formula.

DESCRIPTION OF RUN-OFF DIAGRAMS.

Fig. 12 is a run-off diagram of Hudson and Genesee rivers, Hudson River for 1888-1901, inclusive, and Genesee River for 1890-1898,

[a] Trans. Am. Soc. C. E., Vol. XXXV, p. 241.

inclusive. In preparing this and the following diagrams it sidered that if b off and prec were correctly n the points wo in a regular cu proximately lik shown on figs. 11. Such diagra therefore be tak criterion of the a with which the tions have been It is easier, how measure the run it is to measure cipitation, and when large varia curs, as it does several diagra may first look the precipitati ords. As rega Hudson area, been the writer's to take the rai the northern pl the State weathe as, on the who representing the of the Upper area. With th tion of the ye and 1900 the p fall within from to an inch and of the curve. two years hav ever, been comp a less accurate than the pre ones. It is co therefore, that from 1899 and curves represe rainfall and ru

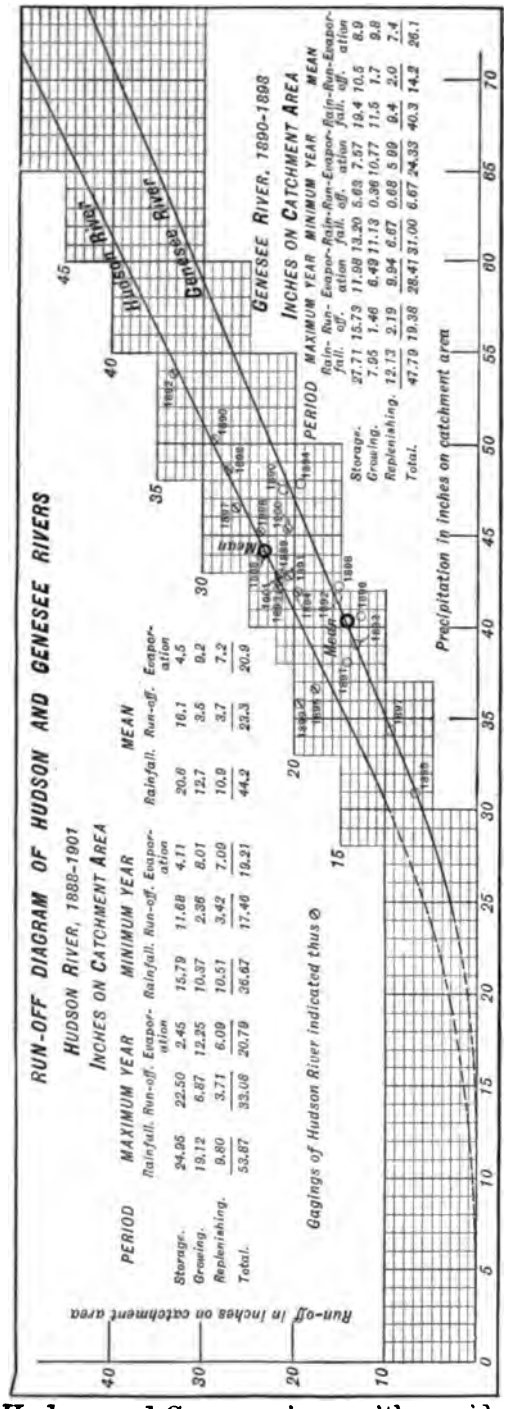


FIG. 12.—Run-off diagram of Hudson and Genesee rivers.

Hudson and Genesee rivers with considerable accuracy.

Fig. 13 shows in a similar manner a run-off diagram for Muskingum iver from 1888 to 1895, inclusive.

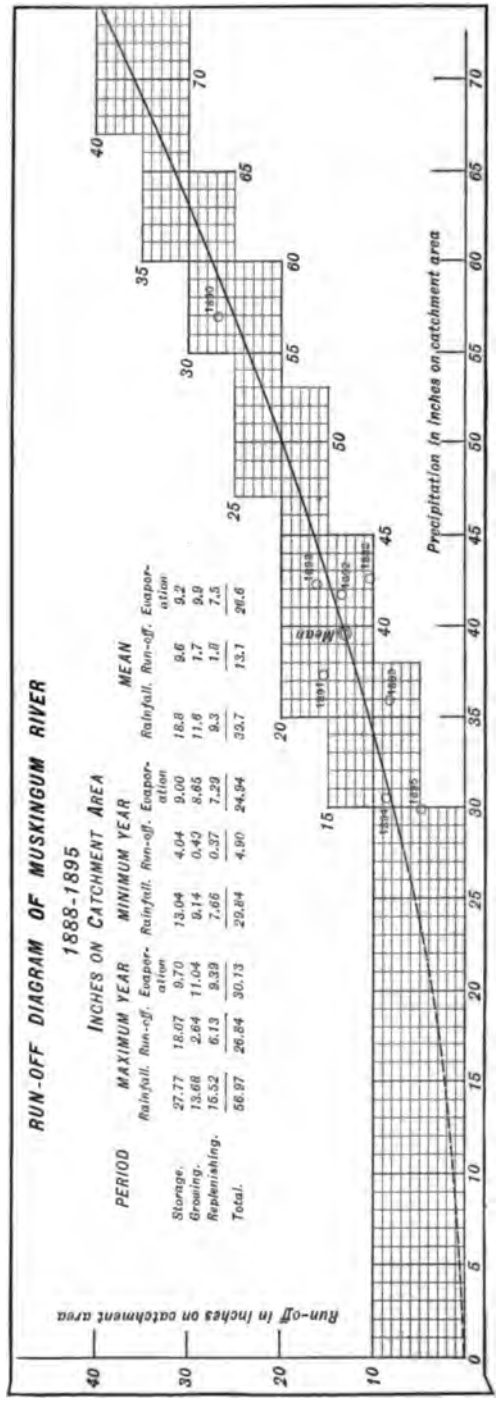


FIG. 13.—Run-off diagram of Muskingum River.

Fig. 14 is a similar diagram for Passaic River from 1877 t inclusive.

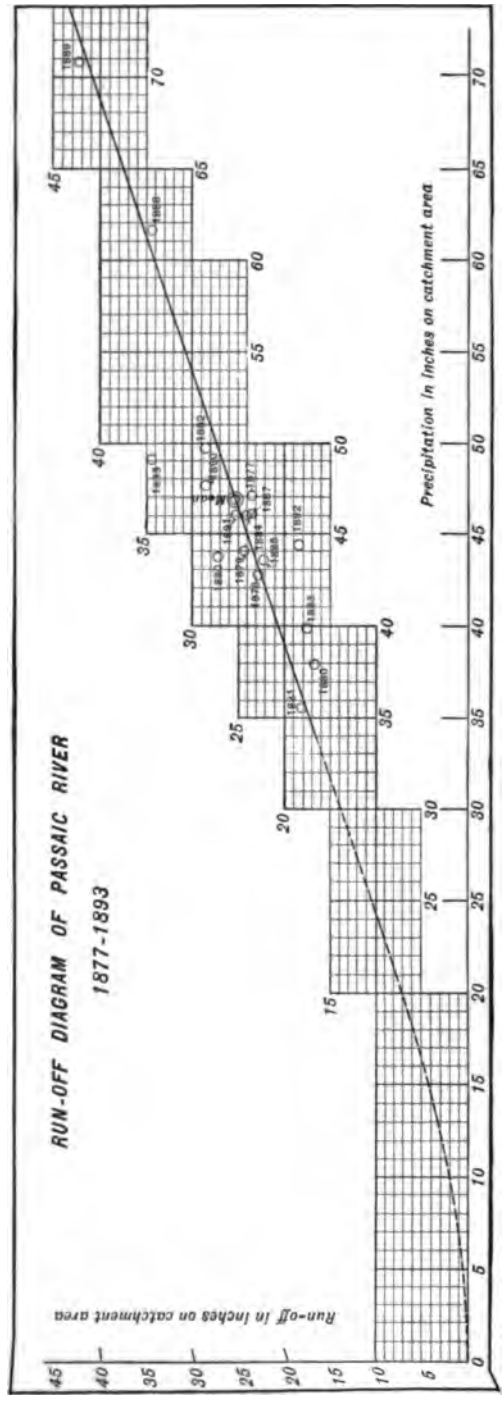

RUN-OFF DIAGRAM OF PASSAIC RIVER
1877-1893
Precipitation in inches on catchment area
Run-off in inches on catchment area

FIG. 14.—Run-off diagram of Passaic River.

Fig. 15 is a similar diagram of Sudbury River from 1875 to 1900, inclusive.

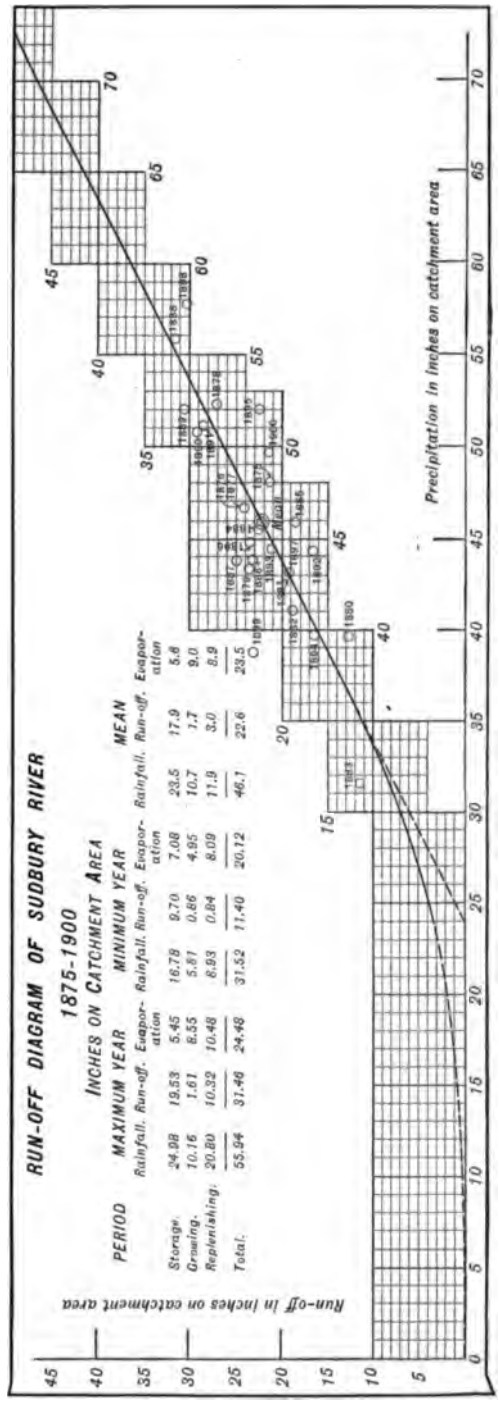

RUN-OFF DIAGRAM OF SUDBURY RIVER
1875-1900
INCHES ON CATCHMENT AREA
PERIOD
MAXIMUM YEAR
MINIMUM YEAR
MEAN
Rainfall. Run-off. Evaporation
Rainfall. Run-off. Evaporation
Rainfall. Run-off. Evaporation
Storage. 24.98 19.53 5.45 16.78 9.70 7.08 23.5 17.9 5.8
Growing. 10.16 1.61 8.55 5.81 0.86 4.95 10.7 1.7 9.0
Replenishing. 20.80 10.32 10.48 8.93 0.84 8.09 11.9 3.0 8.9
Total. 55.94 31.46 24.48 31.52 11.40 20.12 46.1 22.6 23.5
Run-off in inches on catchment area
Precipitation in inches on catchment area

FIG. 15.—Run-off diagram of Sudbury River.

Fig. 16 is a diagram of the revised gagings of Croton River 1877 to 1899, inclusive

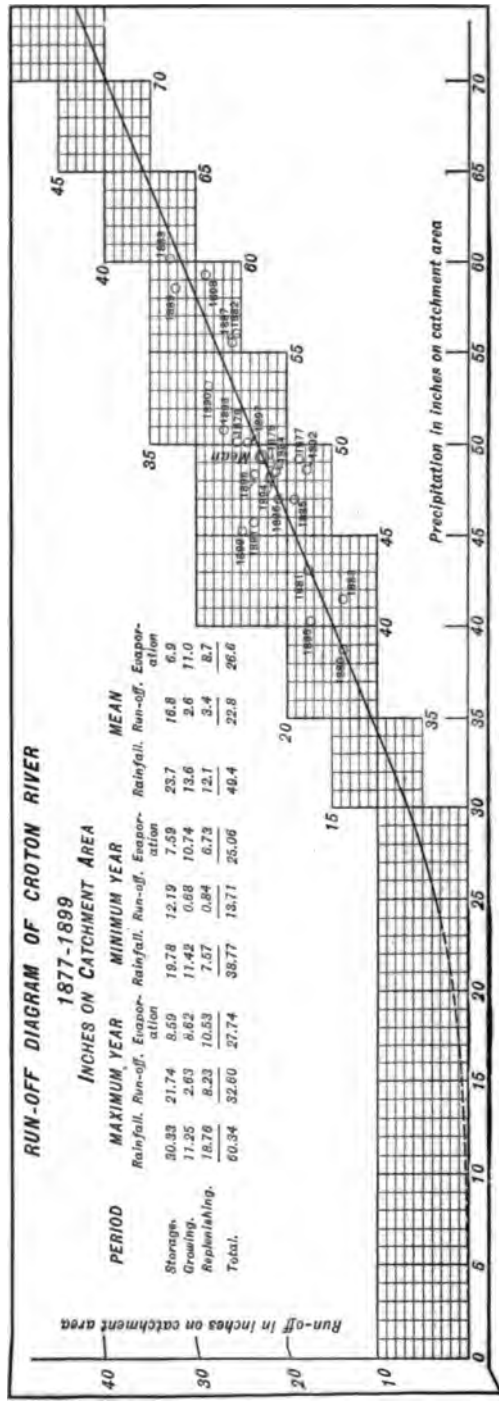
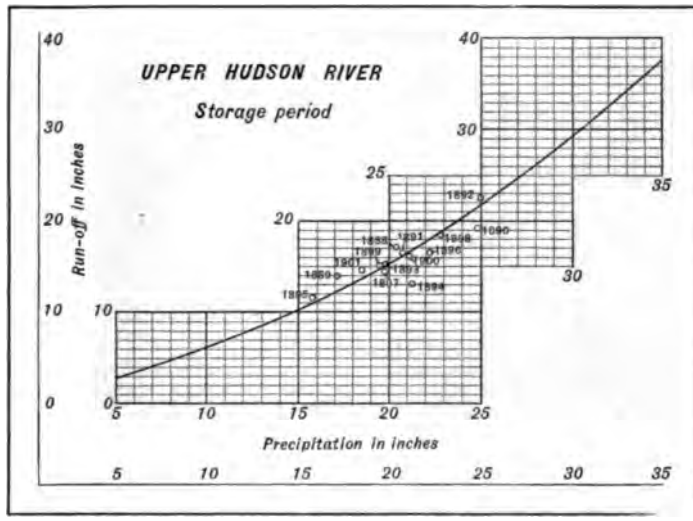

RUN-OFF DIAGRAM OF CROTON RIVER
1877-1899
INCHES ON CATCHMENT AREA
PERIOD
MAXIMUM YEAR
MINIMUM YEAR
MEAN
Rainfall. Run-off. Evaporation
Storage. 30.33 21.74 8.59 19.78 12.19 7.59 23.7 16.8 6.9
Growing. 11.25 2.63 8.62 11.42 0.68 10.74 13.6 2.6 11.0
Replenishing. 18.76 8.23 10.53 7.57 0.84 6.73 12.1 3.4 8.7
Total. 60.34 32.60 27.74 38.77 13.71 25.06 49.4 22.8 26.6
Run-off in inches on catchment area
Precipitation in inches on catchment area
Mean

FIG. 16.—Run-off diagram of Croton River.

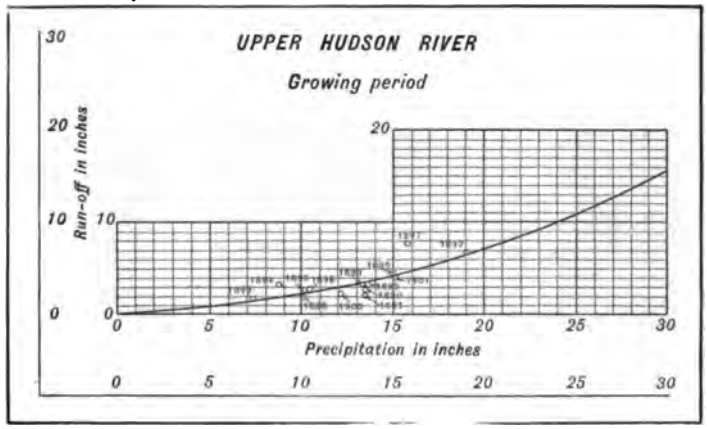
The maximum, minimum, and mean run-off may be obtained from the tabulations on each figure except for Passaic River.

It is evident that proceeding in the same way as for the foregoing diagrams, figs. 12–16, inclusive, diagrams may be prepared for the storage, growing, and replenishing periods, and a curve drawn from which the run-off for a given rainfall may be taken.



G. 17.—Diagram showing the relation between precipitation and run-off in the Upper Hudson River Basin during the storage period.

Fig. 17 is such a diagram for the storage period on the Upper Hudson River for the years 1888–1901, inclusive. This diagram shows that aside from the years 1890 and 1894 the run-offs of this catchment area were substantially accurate during the storage period. It is



IG. 18.—Diagram showing the relation between the precipitation and run-off in the Upper Hudson River Basin during the growing period.

robable that in these two years their accuracy may have been interfered with by ice, although just the cause is not definitely known—may have been in the rainfall.

Fig. 18 is a similar diagram for the Upper Hudson River during the

growing period for the same years. This diagram shows that as from 1897, the run-offs were substantially right during this period

Fig. 19 is a similar diagram for the Upper Hudson River during replenishing period for the same years. This diagram shows that

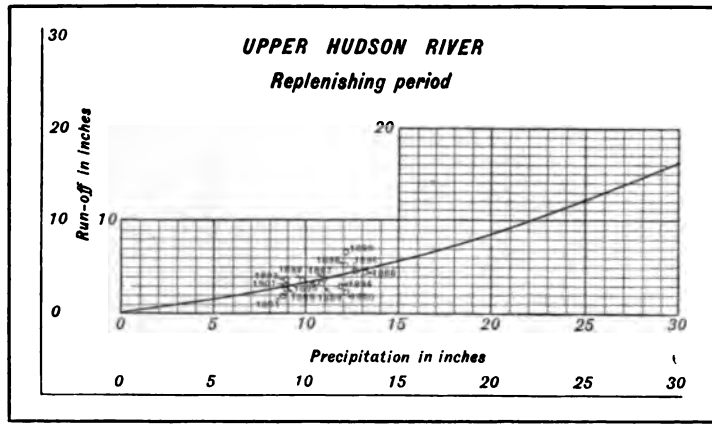


FIG. 19. Diagram showing the precipitation and run-off in the Upper Hudson River Basin ing the replenishing period.

1890 and 1900 there was a discrepancy, which, as in the previc cases, was presumably in the precipitation of that period.

Fig. 20 is a similar diagram for the storage period of Sudbu River. The observations in this case are so scattering that we m safely conclude that ice plays a very important part in the disco

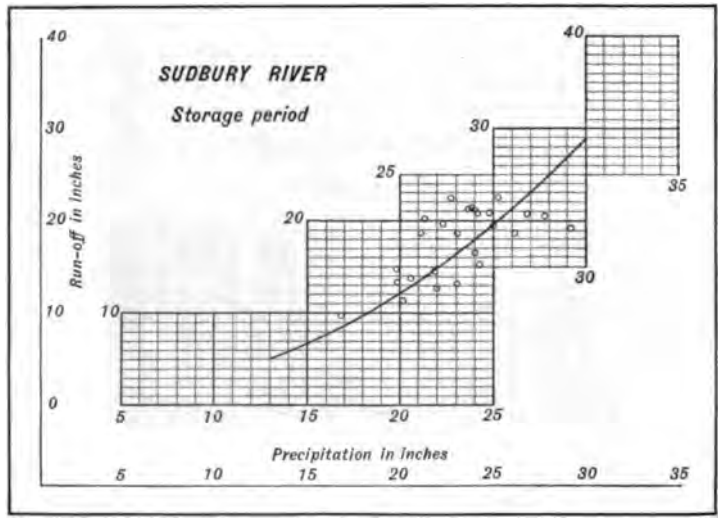


FIG. 20.—Diagram showing the relation between precipitation and run-off in the Sudbury R Basin during the storage period.

ancy of Sudbury River observations during the storage period. Th is, however, during the earlier years, a lack of complete precipitat *observations* on the Sudbury catchment area, although it is not c *sidered* that this is a very important cause, for the reason that

growing and replenishing periods on this stream show much better results than the storage period. The most probable assumption, therefore, seems to be the disturbing effect of ice in the storage period.

Fig. 21 is a similar diagram of Sudbury River for the growing period. With the exception of three years, the observations for this period are very reliable.

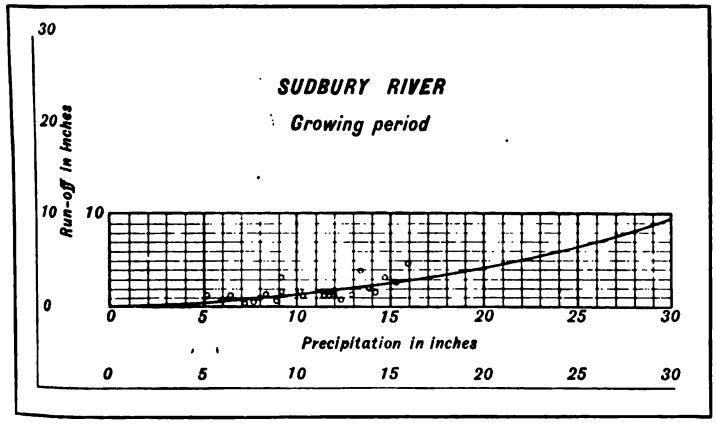
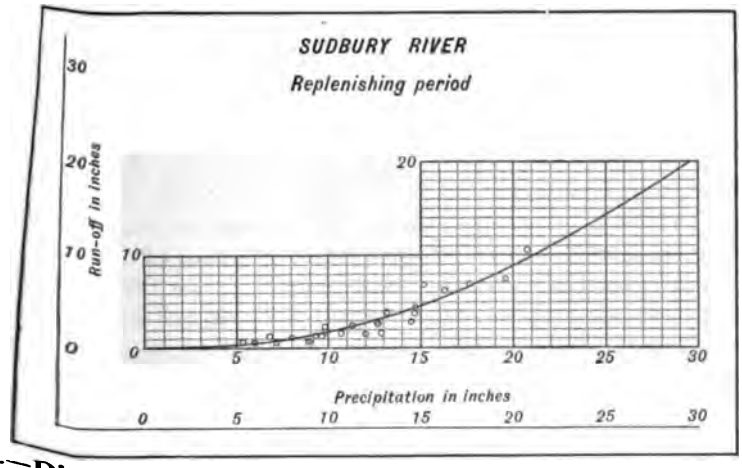


FIG. 21.—Diagram showing the relation between precipitation and run-off in the Sudbury River Basin during the growing period.

Fig. 22 is a similar diagram of Sudbury River for the replenishing period. In this case, the observations are all good except for one year.

Proceeding on similar lines, the writer prepared, several years ago,



2.—Diagram showing the relation between precipitation and run-off in the Sudbury River Basin during the replenishing period.

ries of curves, from which the monthly run-offs may be taken. unfortunately, owing to negative evaporation in the storage d, the individual months of that period were so discordant as to ery *unsatisfactory*. The writer, therefore, does not give any such

diagrams in this connection. His present view is that, for the reason stated, they can not be safely used.

Fig. 23 is a section of Mechanicville dam, over which the gagings of Hudson River have been made.

One or two general conclusions of some interest may be drawn from figs. 12–16, inclusive. For instance, taking the extreme low water as represented by the year 1895, on Muskingum River, at 4.9 inches for the whole year, with a rainfall of 29.8 inches, it is interesting to observe that in the preceding year of 1894, there was a total run-off of 8.7 inches, with a total rainfall of 30.5 inches. That is to say, the rainfall for the year 1894 was 0.7 inch greater than in 1895, but the run-off was 3.8 inches greater. This extreme difference may be ascribed to the difference in the height of ground water. In 1895, ground water stood much lower than in 1893, with the result of a lower run-off.

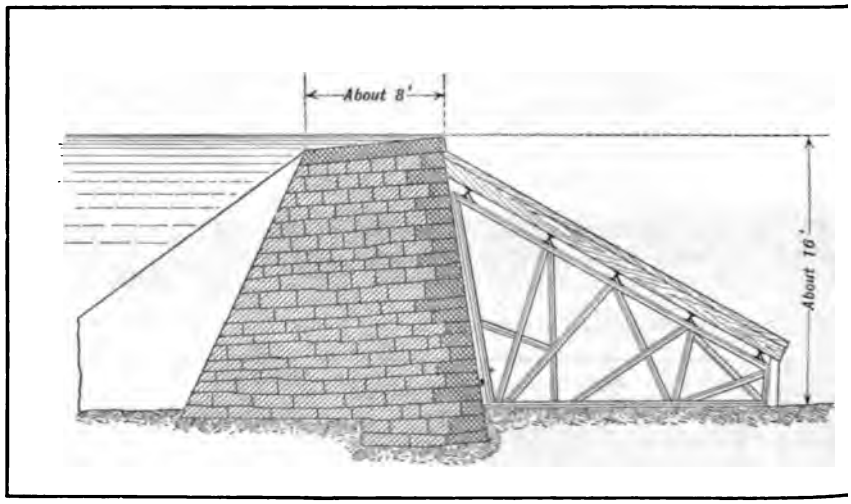


FIG. 23.—Section of Mechanicville dam.

On fig. 12, with a precipitation of 30 inches, the run-off is found to be 6 inches, while on fig. 13, with a precipitation of 30 inches, run off ordinarily may be expected to be about 8 inches. This statement is made on the assumption that the curve is drawn in a mean position, or in such a way as to give average mean results, but it should not be overlooked that Muskingum River observations are too few to draw absolute conclusions. The diagram, fig. 13, shows that there is some lack of accuracy in at least one-half of them.

Fig. 12 shows that on Hudson River, if during any year the total rainfall should sink to 30 inches, the run-off may be expected to be somewhat less than 10 inches, though the modifying effect of full or low ground water may be taken into account in reaching such conclusion. Probably there would be, due to elevation of ground water, a variation of perhaps 2 inches.

On the diagram of Passaic River, fig. 14, 30 inches of precipitation licates 14 inches of run-off. This is very high, and shows that rther study of the Passaic is needed before one can safely accept e results as entirely reliable.

On the diagram of Sudbury River, fig. 15, a precipitation of 30 hes may be expected to produce a run-off of about 7 inches, show- that this stream is, as regards run-off characteristics, very closely ied to Genesee and Muskingum rivers.

On the diagram of Croton River, fig. 16, it is also seen that 30 hes precipitation may be expected to produce a little less than 7 hes of run-off, showing also that this stream has substantially the aracteristics of Genesee River.

n all of the foregoing statements as to minimum run-off, it should understood that the actual quantity appearing in the stream as n-off from a given precipitation will vary, depending on whether und water is high or low at the beginning of the period considered. such statements, therefore, are necessarily approximate—they y have a plus or minus variation from the diagram of one or two hes.

SUMMARY.

n order to assist the discussion, the following summary, which ludes, it is believed, the more important points of the paper, is ewith submitted:

. There is no general expression giving accurately the relation of nfall to run-off. The run-off of a stream is influenced by so many nplex elements that the data are lacking for final conclusions. ery stream is, in effect, a law unto itself. An empirical formula y, however, be made, which will give for some streams approxi- ately the run-off for a series of years.

2. The cause of rainfall is not very well understood, although there one principle upon which there is no disagreement—that in order produce rain, the temperature of the air must be cooled below the w point.

3. The errors in rainfall measurements are so large that one may fely state that nearly all measurements are merely approximations.

4. In view of the foregoing proposition, to carry rainfall measure- ents out to more than one decimal place is an unnecessary refine- ent.

5. As a general statement the minimum rainfall may be placed at om one-half to one-fourth of the maximum.

6. It is uncertain whether rainfall is in any degree increasing.

7. In England there is sometimes an increase of rainfall with crease of elevation,[a] but in the United States the areas are so large

[a] See remarks of H. Somerby Wallis on this point in Monthly Weather Review for April, 1902, 28.

that as soon as one goes away from the influence of the ocean ve frequently this peculiarity does not appear. In a very large numb of cases the reverse is true.

8. Contours can not be satisfactorily drawn on a rainfall map the State of New York until we have a larger number of stations a longer periods of observation.

9. Rainfall and run-off records are conveniently divided into st age, growing, and replenishing periods, such division facilitating co putations and bringing out the salient points. A large percentage the total water supply runs off during the storage period.

10. Assuming that a rainfall record is accurate, it should cov about thirty-five years before it can be relied upon within 2 per cer As to a run-off record, the number of long records are as yet too fe to furnish satisfactory answers to questions concerning run-off.

11. The best unit of measurement is cubic feet per second, and t next best is inches on the catchment area.

12. The run-off of streams has been generally overestimated. Th minimum flow may be as low as from 0.05 to 0.1 of a cubic foot p square mile per second. Streams issuing from sand plains may sho from 0.5 to 0.6 of a cubic foot per square mile per second. General speaking, the range will not be outside of from 0.05 to 0.5 of a cub foot per square mile per second.

13. As regards run-off, streams may be divided into classes, in th first of which will fall streams with a maximum rainfall from 50 to 6 inches and with a maximum run-off somewhat more than one-hal the rainfall, etc. They may be also classified with regard to evapora tion, as will be noted further on.

14. The run-off of streams can not be satisfactorily estimated fron diagrams of monthly rainfall.

15. The run-off of a stream is materially influenced by the numbe of lakes within its catchment area.

16. Generally speaking, maximum-discharge formulas are unsatis factory guides and are hardly worth the trouble their use entails. Exceptions to this may be taken in the use of Dickens and Ryves' formulas.

17. Safe deductions can not be made from an average run-off. What is wanted is a clear statement of the minimum, together with the longest period which it may be expected to occupy.

18. There is very serious danger in using percentages.

19. The influence of the May rainfall is such that when above the normal, stream flow is likely to be well maintained during the summer.

20. As regards delivery of streams, what is wanted in a stream is as large a ground flow as possible, with small evaporation.

21. When rainfall is below the mean for several months, ground water may be expected to become continuously lower, with the result *that the flow* of streams will be less.

22. The run-off of streams will vary with the velocity of wind, pressure, force of vapor, etc.

23. For individual streams an exponential formula is undoubtedly the best. By its use the given data may be more closely represented than in any other manner.

24. Annual run-off diagrams may be taken as a criterion as to the accuracy with which the observations have been made.

25. When a run-off record is given, without the rainfall, the rainfall may be computed by assuming the evaporation and making a series of approximations.

26. The run-off of streams with very great difference in size of catchment areas may be experimentally compared.

27. The extreme low-water period may extend over at least two years and occasionally over three years.

28. In order to clarify the whole matter of stream gagings, what is wanted in the future is a brief, explicit statement of just how the stream was measured, thus enabling hydrologists to judge of the accuracy of the method.

29. There is considerable variation in weir measurements, due to form of weir alone. The formula for a sharp-crested weir can not be applied to any other form without large variation.

30. The several diagrams, as well as the evaporation formula, show that there is no relation between evaporation and mean annual temperature.

31. The laws of evaporation are exhibited in the chapter on "Evaporation relations," by Professor Tate.

32. Evaporation is a persistently uniform element. The tendency is to remain at about the same figure from year to year.

33. In addition to the classification of streams with reference to rainfall, those with large evaporations may be placed in a class by themselves.

34. Streams with large evaporation are, so far as known, always deforested.

35. Negative evaporation exists on all the streams included in the tables. When negative evaporation exceeds more than two consecutive months there is, generally speaking, some doubt about the accuracy of the record.

36. The ground water must be taken into account in order to understand all the peculiarities of flow. A very important effect of forests is in increasing the ground-water flow.

37. It is uncertain whether difference in geology has much influence on run-off, although it appears that porous, sandy soils do considerably affect the result. There are, however, a number of cases which indicate that it may have important influence, although an examination of the evidence shows that the theory that forests materially influence

the run-off is more reasonable than that percolation through geologic formations exercises much influence.

38. So far as present information goes there is little or no relation between topography and the run-off of streams. Deforestation appears to exercise a much more important influence.

39. It is uncertain whether forests in any way influence the quantity of rainfall.

40. The extent of forestation seems to have considerable effect on the run-off of streams, catchments with dense forests showing larger run-off for the same rainfall than those which are deforested. As a tentative proposition it may be said that the removal of forests notably decreases stream flow.

41. The effect of forests is clearly shown on Hudson River.

42. Catchment areas from which municipal water supplies are drawn should be heavily forested. This is a broad proposition merely.

43. If the Croton catchment area had growing upon it a forest from one hundred to one hundred and fifty years old there would probably be, on an average, about 5 inches more annual run-off then there is under present conditions. Nevertheless it would not be a good investment for the city of New York to reforest this area, for the reason that the gain in water supply would not be commensurate with the expense.

The foregoing summary indicates a large number of factors which in some degree affect the run-off of streams. Moreover, only the main factors have been noted; there are many more of less importance.

There is a large amount of useful information on the general subject of the relation of forests to rainfall in Bulletin No. 7 of the Forestry Division of United States Department of Agriculture—Forest Influences—which, since that bulletin is readily obtained, has not been specially referred to here.

Finally, this paper is an attempt to establish a more rational theory of the relation between rainfall and run-off of streams than has thus far obtained.

TABLES.

TABLE NO. 1.—*Muskingum River, 1888–1895, inclusive.*

[Catchment area 5,828 square miles.]

Period.	1888.			1889.			1890.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
Storage	17.16	5.17	11.99	13.52	6.02	7.50	27.77	18.07	9.70
Growing	14.31	1.77	12.54	12.12	1.24	10.88	13.68	2.64	11.04
Replenishing	11.14	3.39	7.75	10.24	.96	9.28	15.52	6.13	9.39
Year	42.61	10.33	32.28	35.88	8.22	27.66	56.97	26.84	30.13
	1891.			1892.			1893.		
Storage	16.72	12.42	4.30	20.39	9.06	11.33	25.04	14.13	10.91
Growing	13.56	1.77	11.79	16.54	3.65	12.89	8.31	1.22	7.09
Replenishing	7.08	1.37	5.71	4.81	.67	4.14	9.01	.85	8.16
Year	37.36	15.56	21.80	41.74	13.38	28.36	42.36	16.20	26.16
				1894.			1895.		
Storage				16.93	7.63	9.30	13.04	4.04	9.00
Growing				4.56	.66	3.90	9.14	.49	8.65
Replenishing				9.02	.41	8.61	7.66	.37	7.29
Year				30.51	8.70	21.81	29.84	4.90	24.94

TABLE NO. 2.—*Genesee River, 1890–1898, inclusive.*

[Catchment area 1,070 square miles.]

Period.	1890.			1891.			1892.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
Storage	[a]23.01	[b]12.96	[b]10.05	18.22	11.88	6.34	19.84	9.38	10.46
Growing	[a]10.52	2.51	8.01	12.78	1.06	11.72	15.30	4.90	10.40
Replenishing	[a]14.01	5.75	8.26	7.12	1.11	6.01	6.55	1.14	5.41
Year	[a]47.54	[b]21.22	[a]26.32	38.12	14.05	24.07	41.69	15.42	26.27
	1893.			1894.			1895.		
Storage	20.05	[b]11.10	[b]9.55	27.71	15.73	11.98	13.20	5.63	7.57
Growing	9.55	[b]1.00	[b]8.55	7.95	1.46	6.49	11.13	.36	10.77
Replenishing	9.10	1.25	7.85	12.13	2.19	9.94	6.67	.68	5.99
Year	39.30	[b]13.35	[b]25.95	47.79	19.38	28.41	31.00	6.67	24.33
	1896.			1897.			1898.		
Storage	17.84	9.25	8.59	15.68	7.31	8.37	18.66	10.40	8.26
Growing	10.28	.83	9.45	11.92	1.34	10.58	14.15	2.05	12.10
Replenishing	12.56	2.72	9.84	6.79	.73	6.06	9.69	2.68	7.01
Year	40.68	12.80	27.88	34.39	9.38	25.01	42.50	15.13	27.37

[a] For years 1890–1892 the run-off is that of Oatka Creek, a tributary of Genesee River, and the rainfall of Oatka Creek catchment area has been taken rather than that of entire upper Genesee area.

[b] Approximate.

TABLE No. 3.—*Croton River, 1868–1899, inclusive.*

[Catchment area=338.8 square miles.]

Period.	1868.			1869.			1870.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
Storage	23.24	17.25	5.99	21.89	15.75	6.14	28.42	19.01	9.
Growing	13.64	5.75	7.89	7.77	2.01	5.76	10.59	1.56	9.
Replenishing	14.85	11.06	3.79	15.09	4.39	10.70	10.09	.96	9.
Year	51.73	34.06	17.67	44.75	22.15	22.60	49.10	21.53	27.

	1871.			1872.			1873.		
Storage	19.83	9.72	10.11	14.57	10.31	4.26	22.19	18.52	3.67
Growing	16.04	2.61	13.43	14.33	3.01	11.32	8.65	1.54	7.11
Replenishing	11.95	5.65	6.30	10.75	4.38	6.37	12.58	3.20	9.38
Year	47.82	17.98	29.84	39.65	17.70	21.95	43.42	23.26	20.16

	1874.			1875.			1876.		
Storage	23.74	22.86	0.88	17.10	14.81	2.29	22.64	19.89	2.75
Growing	12.30	2.77	9.53	16.45	5.86	10.59	7.14	1.07	6.07
Replenishing	8.68	1.60	7.08	10.33	3.41	6.92	10.11	1.35	8.76
Year	44.72	27.23	17.49	43.88	24.08	19.80	39.89	22.31	17.58

	1877.			1878.			1879.		
Storage	17.49	12.36	5.13	20.99	14.19	6.80	25.17	20.81	4.36
Growing	13.17	.96	12.21	11.29	2.57	8.72	18.09	2.63	15.46
Replenishing	18.46	5.49	12.97	16.72	5.01	11.71	6.96	1.88	5.08
Year	49.12	18.81	30.31	49.00	21.77	27.22	50.22	25.32	24.90

	1880.			1881.			1882.		
Storage	19.78	12.19	7.59	24.53	14.79	9.74	27.91	16.85	11.06
Growing	11.42	.68	10.74	9.61	1.95	7.66	9.03	2.06	6.97
Replenishing	7.57	.84	6.73	8.96	.97	7.99	19.10	6.21	12.89
Year	38.77	13.71	25.06	43.10	17.71	25.39	56.04	25.12	30.92

	1883.			1884.			1885.		
Storage	19.03	11.37	7.66	24.81	16.85	7.96	21.86	15.36	6.50
Growing	12.10	1.09	11.01	15.72	2.34	13.38	12.89	.88	12.01
Replenishing	10.41	1.28	9.13	8.01	1.87	6.14	12.23	2.92	9.31
Year	41.54	13.74	27.80	48.54	21.06	27.48	46.98	19.16	27.82

	1886.			1887.			1888.		
Storage	25.45	18.16	7.29	23.05	16.44	6.61	30.33	21.74	8.59
Growing	11.68	1.53	10.15	24.75	6.71	18.04	11.25	2.63	8.62
Replenishing	9.82	1.23	8.59	7.78	2.60	5.18	18.76	8.23	10.53
Year	46.95	20.92	26.03	55.58	25.75	29.83	60.34	32.60	27.74

TABLE No. 3.—*Croton River, 1868–1899, inclusive*—Continued.

riod.	1889.			1890.			1891.		
	Rainfall.	Runoff.	Evaporation.	Rainfall.	Runoff.	Evaporation.	Rainfall.	Runoff.	Evaporation.
.....	22.40	16.86	5.54	25.31	19.10	6.21	26.66	21.22	5.44
.....	17.37	6.49	10.88	13.31	2.51	10.80	11.26	1.14	10.12
r	18.83	8.70	10.13	14.60	7.02	7.58	7.78	1.11	6.67
.....	58.60	32.05	26.55	53.22	28.63	24.59	45.70	23.47	22.23
	1892.			1893.			1894.		
.....	22.93	12.87	10.06	27.34	21.41	5.93	23.24	15.65	7.59
.....	15.37	2.60	12.77	12.39	1.84	10.55	7.95	1.82	6.13
r	10.30	2.31	7.99	11.08	3.51	7.57	17.05	4.41	12.64
.....	48.60	17.78	30.82	50.81	26.76	24.05	48.24	21.88	26.36
	1895.			1896.			1897.		
.....	19.55	14.78	4.77	24.84	18.01	6.83	20.55	14.64	5.91
.....	11.19	1.05	10.14	12.25	2.03	10.22	20.79	6.93	13.86
r	9.54	1.27	8.27	11.27	3.13	8.14	8.76	2.73	6.03
.....	40.28	17.10	23.18	48.36	23.17	25.19	50.10	24.30	25.80
				1898.			1899.		
.....				28.81	20.08	8.73	22.66	21.38	1.28
.....				17.17	4.83	12.34	12.19	1.57	10.62
r				13.36	3.99	9.37	10.37	1.96	8.41
.....				59.34	28.90	30.44	45.22	24.91	20.31
				Mean 1868–1876, inclusive.			Mean 1877–1899, inclusive.		
.....				21.51	16.46	5.05	23.68	16.83	6.85
.....				11.88	2.91	8.97	13.58	2.57	11.01
r				11.61	4.00	7.61	12.08	3.42	8.66
.....				45.00	23.37	21.63	49.33	22.81	26.52

TABLE NO. 4.—*Lake Cochituate, 1863–1900, inclusive.*

[Catchment area = 18.9 square miles, not including catchment of Dudley Pond.]

Period.	1863.			1864.			1865.		
	Rain fall.	Run off.	Evaporation.	Rain fall.	Run off.	Evaporation.	Rain fall.	Run off.	Evaporation.
Storage	29.49	16.31	13.18	24.70	14.44	10.26	29.63	17.28	12.35
Growing	21.71	5.15	16.56	5.20	1.58	3.62	7.37	1.27	6.10
Replenishing	16.49	5.25	11.24	13.47	3.17	10.30	13.43	2.15	11.28
Year	67.69	26.71	40.98	43.37	19.19	24.18	50.43	20.70	29.73
	1866.			1867.			1868.		
Storage	22.87	9.38	13.49	27.02	16.47	10.55	23.02	16.95	6.07
Growing	22.13	2.94	19.19	20.67	3.34	17.33	12.49	3.22	9.27
Replenishing	16.31	3.26	13.05	10.98	2.43	8.55	15.65	4.76	10.89
Year	61.31	15.58	45.73	58.67	22.44	36.43	51.16	24.93	26.23
	1869.			1870.			1871.		
Storage	28.91	12.83	16.08	36.50	23.72	12.78	19.77	10.19	9.58
Growing	8.65	2.39	6.26	9.18	1.91	7.27	11.72	2.15	9.57
Replenishing	21.25	4.77	16.48	13.00	2.85	10.15	13.85	2.38	11.47
Year	58.81	19.99	38.82	58.68	28.48	30.20	45.34	14.72	30.62
	1872.			1873.			1874.		
Storage	14.51	8.88	5.63	20.00	18.51	1.49	20.76	16.23	4.53
Growing	19.58	2.95	16.63	11.63	2.47	9.16	12.78	3.83	8.95
Replenishing	14.20	5.39	8.81	13.27	4.68	8.59	4.64	1.63	3.01
Year	48.29	17.22	31.07	44.90	25.66	19.24	38.18	21.69	16.49
	1875.			1876.			1877.		
Storage	17.80	10.76	7.04	20.45	14.91	5.54	21.61	15.65	5.96
Growing	15.34	2.35	12.99	13.28	1.64	11.64	8.76	2.24	6.52
Replenishing	13.11	3.75	9.36	12.57	3.22	9.35	15.54	4.31	11.23
Year	46.25	16.86	29.39	46.30	19.77	26.53	45.91	22.20	23.71
	1878.			1879.			1880.		
Storage	23.38	19.08	4.30	19.96	16.83	3.13	18.47	8.55	9.92
Growing	13.74	2.07	11.67	13.95	2.05	11.90	12.06	.62	11.44
Replenishing	12.36	3.09	9.27	5.62	1.93	3.69	6.34	1.56	4.78
Year	49.48	24.24	25.24	39.53	20.81	18.72	36.87	10.73	26.14
	1881.			1882.			1883.		
Storage	22.23	12.74	9.49	23.10	12.39	10.71	16.62	8.31	8.31
Growing	8.74	1.56	7.18	6.50	.75	5.75	5.08	.16	4.92
Replenishing	8.85	1.25	7.60	12.35	2.39	9.96	8.53	1.62	6.91
Year	39.82	15.55	24.27	41.95	15.53	26.42	30.23	10.09	20.14

No. 4.—*Lake Cochituate, 1863–1900, inclusive*—Continued.

	1884.			1885.			1886.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
.....	24.79	15.70	9.09	22.80	11.90	10.90	24.14	18.97	5.17
.....	12.79	1.54	11.25	11.70	.76	10.94	8.26	.57	7.69
.....	5.82	1.09	4.73	12.15	3.09	9.06	11.12	1.92	9.20
.....	43.40	18.33	25.07	46.65	15.75	30.90	43.52	21.46	22.06
		1887.			1888.			1889.	
.....	26.97	19.91	7.06	24.22	15.44	8.78	21.79	17.26	4.53
.....	10.05	2.87	7.18	10.06	1.94	8.12	16.84	6.24	10.60
.....	6.53	1.83	4.70	20.79	9.09	11.70	14.56	6.65	7.91
.....	43.55	24.61	18.94	55.07	26.47	28.60	53.19	30.15	23.04
		1890.			1891.			1892.	
.....	23.42	17.17	6.25	27.73	28.21	−0.48	21.11	12.47	8.64
.....	7.43	2.20	5.23	11.68	1.99	9.69	10.49	1.38	9.11
.....	17.82	6.29	11.53	9.10	2.38	6.72	9.43	2.26	7.17
.....	48.67	25.66	23.01	48.51	32.58	15.93	41.03	16.11	24.92
		1893.			1894.			1895.	
.....	22.84	12.40	10.44	21.00	10.25	10.75	20.18	11.29	8.89
.....	11.01	1.90	9.11	7.79	1.24	6.55	11.79	1.45	10.34
.....	7.58	2.51	5.07	10.94	2.04	8.90	18.66	6.17	12.49
.....	41.43	16.81	24.62	39.73	13.53	26.20	50.63	18.91	31.72
		1896.			1897.			1898.	
.....	20.91	15.96	4.95	19.87	11.05	8.82	26.61	16.15	10.46
.....	7.69	1.55	6.14	12.34	2.57	9.77	12.71	2.45	10.26
.....	14.74	3.70	11.04	9.92	2.58	7.34	16.76	4.26	12.50
.....	43.34	21.21	22.13	42.13	16.20	25.93	56.08	22.86	33.22
					1899.			1900.	
.....				22.31	18.38	3.93	28.30	14.09	14.21
.....				8.16	.23	7.93	9.25	1.49	7.76
.....				10.01	1.63	8.38	13.01	2.72	10.29
.....				40.48	20.24	20.24	50.56	18.30	32.26
				Mean for 5 years, 1896–1900, inclusive.			Mean for 38 years, 1863–1900, inclusive.		
.....				23.00	15.13	8.47	23.15	14.92	8.23
.....				10.03	1.66	8.37	11.59	2.08	9.51
.....				12.89	2.98	9.91	12.38	3.32	9.06
.....				46.52	19.77	26.75	47.13	20.32	26.81

TABLE NO. 5.—*Sudbury River, 1875–1900, inclusive.*

[Catchment area, 1875–1878, inclusive 77.76 square miles; 1879–80=78.24 square miles; 1881–1899=75.2 square miles.]

Period	1875.			1876.			1877.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation
Storage	19.78	14.69	5.09	21.37	20.10	1.27	23.07	18.71	4.3
Growing	15.34	2.78	12.56	12.89	1.43	11.46	9.08	1.61	7.4
Replenishing	13.11	3.76	9.35	12.62	2.61	10.01	14.64	3.68	10.9
Year	48.23	21.23	27.00	46.88	24.14	22.74	46.77	24.00	22.7

	1878.			1879.			1880.		
Storage	23.91	21.05	2.86	23.84	21.19	2.65	20.15	11.19	8.96
Growing	13.79	1.95	11.84	14.23	1.70	12.53	12.42	.83	11.59
Replenishing	14.73	4.12	10.61	5.37	.72	4.65	7.13	.67	6.46
Year	52.43	27.12	25.31	43.44	23.61	19.83	39.70	12.69	27.01

	1881.			1882.			1883.		
Storage	24.27	15.07	9.20	23.99	16.33	7.66	16.78	9.70	7.08
Growing	9.10	3.07	6.03	5.10	1.17	3.93	5.81	.86	4.95
Replenishing	9.66	1.35	8.31	11.96	1.42	10.54	8.93	.84	8.09
Year	43.03	19.49	23.54	41.05	18.92	22.13	31.52	11.40	20.12

	1884.			1885.			1886.		
Storage	27.78	20.38	7.40	21.90	14.36	7.54	24.19	20.75	3.44
Growing	11.76	1.58	10.18	11.47	1.27	10.20	8.83	.72	8.11
Replenishing	5.98	.53	5.45	12.61	2.84	9.77	10.78	1.62	9.16
Year	45.52	22.49	23.03	45.98	18.47	27.51	43.80	23.09	20.71

	1887.			1888.			1889.		
Storage	25.28	22.43	2.85	24.98	19.53	5.45	21.14	18.71	2.43
Growing	11.69	1.30	10.39	10.16	1.61	8.55	15.91	4.81	11.10
Replenishing	6.93	1.17	5.66	20.80	10.32	10.48	15.15	6.97	8.18
Year	43.80	24.90	18.90	55.94	31.46	24.48	52.20	30.49	21.71

	1890.			1891.			1892.		
Storage	24.77	20.87	3.90	29.96	25.90	4.06	23.15	13.12	10.03
Growing	8.36	1.41	6.95	11.89	1.27	10.62	11.43	1.62	9.81
Replenishing	17.71	6.94	10.77	9.30	1.25	8.05	9.81	1.82	7.99
Year	50.84	29.22	21.62	51.15	28.42	22.73	44.39	16.56	27.83

TABLE No. 5.—*Sudbury River, 1875–1900, inclusive*—Continued.

Period.	1893.			1894.			1895.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
Storage	26.13	18.72	7.41	21.94	12.57	9.37	20.52	13.77	6.75
Growing	10.36	1.26	9.10	6.44	1.38	5.06	11.96	1.12	10.84
Replenishing	7.49	1.13	6.36	11.41	2.37	9.04	19.61	7.41	12.20
Year	44.48	21.11	23.37	39.79	16.32	23.47	52.09	22.30	29.79

	1896.			1897.			1898.		
Storage	22.30	19.64	2.66	19.88	13.23	6.65	26.81	20.65	6.16
Growing	8.13	.96	7.17	13.41	3.88	9.53	14.74	3.29	11.45
Replenishing	14.50	2.87	11.63	9.81	2.06	7.75	16.26	6.14	10.12
Year	44.93	23.47	21.46	43.10	19.17	23.93	57.81	30.08	27.73

	1899.			1900.		
Storage	22.73	22.28	0.45	29.13	19.12	10.01
Growing	7.16	.09	7.07	7.67	.46	7.21
Replenishing	8.82	.90	7.92	12.89	1.58	11.31
Year	38.71	23.27	15.44	49.69	21.16	28.53

	Mean for 5 years, 1896–1900, inclusive.			Mean for whole period, 1875–1900, inclusive.		
Storage	24.17	18.98	5.19	23.45	17.85	5.60
Growing	10.22	1.74	8.48	10.74	1.67	9.06
Replenishing	12.46	2.71	9.75	11.86	2.96	8.90
Year	46.85	23.43	23.42	43.05	22.48	23.56

TABLE NO. 6.—*Mystic Lake, 1878–1895, inclusive.*

[Catchment area—26.9 square miles.]

Period.	1878.			1879.			1880.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	E r
Storage	25.22	18.43	6.79	19.42	16.40	3.02	17.28	9.34	
Growing	13.65	2.37	11.28	11.85	2.21	9.64	12.36	1.72	
Replenishing	13.83	3.02	10.81	5.13	1.27	3.86	6.02	1.25	
Year	52.70	23.82	28.88	36.40	19.88	16.52	35.66	12.31	
	1881.			1882.			1883.		
Storage	23.16	14.02	9.14	22.69	12.47	10.22	16.24	7.41	
Growing	10.11	3.27	6.84	5.49	1.38	4.11	5.29	1.04	
Replenishing	7.85	1.10	6.75	12.03	1.50	10.53	8.93	.90	
Year	41.12	18.39	22.73	40.21	15.35	24.86	30.46	9.44	
	1884.			1885.			1886.		
Storage	24.21	16.57	7.04	21.35	11.03	10.32	24.47	20.82	
Growing	13.21	2.03	11.18	12.35	1.87	10.48	8.49	1.21	
Replenishing	5.40	.85	4.55	13.25	3.43	9.82	9.87	1.58	
Year	42.82	19.45	23.37	46.95	16.33	30.62	42.83	23.61	
	1887.			1888.			1889.		
Storage	25.83	17.44	8.39	24.03	16.09	7.94	23.17	17.47	
Growing	14.24	3.49	10.75	10.66	1.77	8.89	15.69	5.27	
Replenishing	7.59	1.76	5.83	20.37	9.09	11.28	13.94	4.76	
Year	47.66	22.69	24.97	55.06	26.95	28.11	52.80	27.50	
	1890.			1891.			1892.		
Storage	24.35	18.66	5.69	27.67	26.79	0.88	21.35	11.58	
Growing	9.28	2.81	6.47	11.49	1.87	9.62	11.55	2.32	
Replenishing	13.92	5.14	8.78	9.50	1.56	7.94	8.47	2.08	
Year	47.55	26.61	20.94	48.66	30.22	18.44	41.37	15.98	
	1893.			1894.			1895.		
Storage	23.09	15.42	7.67	21.34	11.14	10.20	18.50	10.34	
Growing	9.55	2.20	7.35	6.69	1.78	4.91	13.41	1.82	
Replenishing	8.36	1.67	6.69	11.59	1.85	9.74	18.50	4.09	
Year	41.00	19.29	27.71	39.62	14.77	24.85	50.41	16.25	

TABLE NO. 7.—*Neshaminy Creek, 1884–1899, inclusive.*

[Catchment area = 139.3 square miles.]

Period.	1884.			1885.			1886.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
Storage	25.77	25.61	0.16	20.13	17.85	2.28	26.61	21.45	5.16
Growing	13.71	1.85	11.86	10.25	1.08	9.17	12.67	1.87	10.80
Replenishing	7.05	.45	6.60	11.22	1.73	9.49	7.60	.66	6.94
Year	46.53	27.91	18.62	41.60	20.66	20.94	46.88	23.98	22.90

	1887.			1888.			1889.		
Storage	21.88	15.92	5.96	26.48	21.17	5.31	22.32	13.44	8.88
Growing	19.26	4.44	14.82	11.83	1.01	10.82	22.42	10.00	12.42
Replenishing	7.59	1.03	6.56	14.18	6.02	8.16	22.18	12.37	9.81
Year	48.73	21.39	27.34	52.49	28.20	24.29	66.92	35.81	31.11

	1890.			1891.			1892.		
Storage	22.06	14.85	7.21	23.48	17.74	5.74	22.55	15.01	7.54
Growing	14.28	2.15	12.13	15.90	2.53	13.37	11.58	1.31	10.27
Replenishing	10.23	3.33	6.90	8.04	2.34	5.70	10.13	1.94	8.19
Year	46.57	20.33	26.24	47.46	22.65	24.81	44.26	18.26	26.00

	1893.			1894.			1895.		
Storage	22.16	18.52	3.64	26.68	18.16	8.52	20.97	15.84	5.13
Growing	12.21	1.70	10.51	8.95	1.82	7.13	11.41	2.07	9.34
Replenishing	11.07	3.74	7.33	16.45	6.12	10.33	6.21	.24	5.97
Year	45.44	23.96	21.48	52.08	26.10	25.98	38.59	18.15	20.44

				1896.			1897.		
Storage				20.52	11.54	8.98	19.28	10.60	8.68
Growing				10.80	1.65	9.15	17.70	6.50	11.20
Replenishing				12.65	3.41	9.24	9.06	2.11	6.95
Year				43.97	16.60	27.37	46.04	19.21	26.83

				1898.			1899.		
Storage				25.68	16.87	8.81	23.09	20.50	2.59
Growing				12.34	1.69	10.65	9.41	1.76	7.65
Replenishing				12.80	3.33	9.47	10.91	1.96	8.95
Year				50.82	21.89	28.93	43.41	24.22	19.19

TABLE NO. 8.—*Perkiomen Creek, 1884–1899, inclusive.*

[Catchment area=152 square miles.]

Period.	1884.			1885.			1886.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
Storage	25.25	25.19	0.06	20.47	15.29	5.18	26.03	19.74	6.29
Growing	15.53	4.07	11.46	9.83	1.68	8.15	11.76	3.35	8.41
Replenishing	7.54	1.59	5.95	9.49	2.38	7.11	9.00	2.02	6.98
Year	48.32	30.85	17.47	39.79	19.35	20.44	46.79	25.11	21.68
	1887.			1888.			1889.		
Storage	21.63	14.66	6.97	27.48	19.67	7.81	22.99	14.28	8.71
Growing	17.26	4.26	13.00	12.42	2.17	10.25	23.38	10.02	13.36
Replenishing	6.70	1.45	5.25	14.18	7.40	6.78	20.45	11.81	8.64
Year	45.59	20.37	25.22	54.08	29.24	24.84	66.82	36.11	30.71
	1890.			1891.			1892.		
Storage	24.68	18.15	6.58	22.89	17.35	5.54	23.64	15.89	7.75
Growing	14.35	3.11	11.24	18.32	3.25	15.07	11.06	2.38	8.68
Replenishing	10.31	4.52	5.79	8.15	2.69	5.46	9.33	2.66	6.67
Year	49.34	25.78	23.56	49.36	23.29	26.07	44.03	20.93	23.10
	1893.			1894.			1895.		
Storage	22.16	17.21	4.95	24.37	15.77	8.60	23.22	15.51	7.71
Growing	12.20	1.82	10.38	8.77	2.05	6.72	10.88	1.32	9.56
Replenishing	10.18	3.33	6.85	15.40	5.18	10.22	6.25	.75	5.50
Year	44.54	22.36	22.18	48.54	23.00	25.54	40.35	17.58	22.77
				1896.			1897.		
Storage				19.99	10.26	9.73	20.00	12.37	7.63
Growing				15.05	2.83	12.22	13.69	3.08	10.61
Replenishing				14.62	4.19	10.43	10.07	2.26	7.81
Year				49.66	17.28	32.38	43.76	17.71	26.05
				1898.			1899.		
Storage				24.24	15.74	8.50	22.79	20.49	2.30
Growing				9.98	1.39	8.59	14.12	2.46	11.66
Replenishing				13.85	3.90	9.95	11.36	4.01	7.35
Year				48.07	21.03	27.04	48.27	26.96	21.31

TABLE No. 9.—*Tohickon Creek, 1884–1898, inclusive.*

[Catchment area=102.2 square miles.]

Period.	1884.			1885.			1886.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
.....	28.06	27.27	−1.21	21.86	19.45	2.41	28.54	27.79	0.75
.....	17.52	6.53	10.99	11.31	1.54	9.77	11.10	2.27	8.83
ng	7.97	1.35	6.62	10	2.94	7.06	9.05	2.04	7.01
.....	51.55	35.15	16.40	43.17	23.93	19.24	48.69	32.10	16.59
	1887.			1888.			1889.		
.....	21.60	18.44	3.16	28.52	27.37	1.15	25.13	17.82	7.31
.....	19.19	4.80	14.39	12.96	1.99	10.97	23.90	12.45	11.45
ng	6.71	.91	5.80	16.04	10.14	5.90	21.34	13.70	7.64
.....	47.50	24.15	23.35	57.52	39.50	18.02	70.37	43.97	26.40
	1890.			1891.			1892.		
.....	25.09	19.01	6.08	23.07	20.23	2.84	23.43	19.76	3.67
.....	15.49	2.54	12.95	19.77	4.99	14.78	11.22	1.52	9.70
ng	10.20	5.45	4.75	7.16	2.03	5.13	10.65	3.47	7.18
.....	50.78	27	23.78	50	27.25	22.75	45.30	24.75	20.55
	1893.			1894.			1895.		
.....	22.82	22.05	0.77	27.04	21.65	5.39	21.35	19.91	1.44
.....	14.82	2.10	12.72	6.95	.84	6.11	12.45	1.46	10.99
ng	11.31	4.06	7.25	17.63	8.11	9.52	6.63	.28	6.35
.....	48.95	28.21	20.74	51.62	30.60	21.02	40.43	21.65	18.78
	1896.			1897.			1898.		
.....	21.69	12.30	9.39	20.82	13.93	6.89	26.40	21.20	5.20
.....	13.76	2.91	10.85	17.32	5.12	12.20	10.87	1	9.87
ng	12.58	4.52	8.06	8.78	1.98	6.80	13.80	5.19	8.61
.....	48.03	19.73	28.30	46.92	21.03	25.89	51.07	27.39	23.68

TABLE No. 10.—*Hudson River, 1888–1901, inclusive.*

[Catchment area = 4,500 square miles.]

Period.	1888.			1889.			1890.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
Storage	20.40	17.06	3.34	17.10	14.04	3.06	24.75	19.28	5.47
Growing	10.25	2.05	8.20	15.05	4.26	10.79	13.50	2.85	10.65
Replenishing	13.27	4.53	8.74	10.81	3.41	7.40	12.10	6.81	5.29
Year	43.92	a 28.64	20.28	a 42.96	21.71	21.25	a 50.35	28.94	21.41

	1891.			1892.			1893.		
Storage	20.69	16.59	4.10	24.95	22.50	2.45	19.83	15.20	4.63
Growing	13.49	2.07	11.42	19.12	6.87	12.25	13.37	3.12	10.25
Replenishing	8.78	1.90	6.88	9.80	3.71	6.09	8.98	3.59	5.39
Year	42.96	20.56	22.40	53.87	33.08	20.79	42.18	21.91	20.27

	1894.			1895.			1896.		
Storage	21.37	13.18	8.19	15.79	11.68	4.11	22.17	16.52	5.65
Growing	8.73	3.20	5.53	10.37	2.36	8.01	10.25	2.53	7.72
Replenishing	11.87	2.99	8.88	10.51	3.42	7.09	12.79	4.58	8.21
Year	41.97	19.37	22.60	36.67	17.46	19.21	45.21	23.62	21.58

	1897.			1898.			1899.		
Storage	19.77	14.60	5.17	22.80	18.61	4.19	19.48	15.15	4.33
Growing	15.80	7.79	8.01	13.52	8.24	10.28	7.40	1.63	5.77
Replenishing	10.94	3.80	7.14	12.19	5.27	6.92	8.91	2.76	6.15
Year	46.51	26.19	20.32	48.51	27.12	21.39	35.79	19.54	16.25

				1900.			1901.		
Storage				21.13	16.12	5.01	18.47	14.84	3.63
Growing				12.11	2.30	9.81	15.09	4.02	11.07
Replenishing				12.17	2.25	9.92	9.02	3	6.02
Year				45.41	20.67	24.74	42.58	21.86	20.72

a Approximate.

TABLE NO. 11.—*Pequannock River, 1891–1899, inclusive.*

[Catchment area=63.7 square miles.]

Period.	1891.			1892.			1893.		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
ge	26.78	17.49	9.29	19.54	18.11	1.43	24.70	23.62	1.08
ing	12.52	2.21	10.31	12.83	3.46	9.37	13.02	2.53	10.49
nishing	7.23	2.97	4.26	9.17	2.23	6.94	10.72	4.44	6.28
Year	46.53	22.67	23.86	41.54	23.80	17.74	48.44	30.59	17.85
	1894.			1895.			1896.		
ge	20.29	18.59	1.70	19.69	18.08	1.61	25.62	19.29	6.33
ing	5.81	2.20	3.61	10.07	1.66	8.41	13.51	3.47	10.04
nishing	16.33	8.33	8	8.16	1.37	6.79	14.52	7.18	7.34
Year	42.43	29.12	13.31	37.92	21.11	16.81	53.65	29.94	23.71
	1897.			1898.			1899.		
ge	21.05	17.57	3.48	27.29	22.74	4.55	22.29	21.95	0.34
ing	21.31	8.10	13.21	12.24	2.48	9.76	12.57	1.88	10.69
nishing	9.50	2.83	6.67	13.48	3.54	9.94	10.96	2.74	8.22
Year	51.86	28.50	23.36	53.01	28.76	24.25	45.82	26.57	19.25

TABLE No. 12.—*Connecticut River, 1872–1885, inclusive.*

[Catchment area = 10,234 square miles.]

Period.	1872.			1873.[a]			1874.[a]		
	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.	Rainfall.	Run-off.	Evaporation.
Storage	14.92	13.30	1.62	18.16	21.80	− 3.64	23.08	23.04	0
Growing	18.96	6.29	12.67	10.11	2.71	7.40	14.37	6.62	7
Replenishing	12.42	6.64	5.78	15.04	5.22	9.82	7.76	2.15	5
Year	46.30	26.23	20.07	43.31	29.73	13.58	45.21	31.81	13

Period.	1875.			1876.[a]			1877.		
Storage	17.51	15.47	2.04	22.50	24.74	− 2.24	18.09	12.68	5.41
Growing	14.55	3.80	10.75	12.51	3.35	9.16	14.00	2.91	11.09
Replenishing	11.33	3.60	7.76	10.57	2.28	8.29	13.08	5.27	7.81
Year	43.42	22.87	20.55	45.58	30.37	15.21	45.17	20.86	24.31

Period.	1878.			1879.			1880.		
Storage	21.88	18.02	3.86	23.19	21.49	1.70	18.29	14.78	3.51
Growing	13.59	3.45	10.14	16.07	2.92	13.15	11.82	2.45	9.37
Replenishing	10.56	3.06	7.50	9.48	2.93	6.55	11.58	2.62	8.96
Year	46.03	24.53	21.50	48.74	27.34	21.40	41.69	19.85	21.84

Period.	1881.			1882.			1883.		
Storage	20.83	16.02	4.81	[b]20.50	12.14	8.36	[b]12.85	8.73	4.12
Growing	11.30	2.93	8.37	[b]11.45	3.35	8.10	[b]13.50	2.51	10.99
Replenishing	11.38	3.39	7.99	[b]6.50	2.17	4.33	[b]6.20	1.37	4.83
Year	43.51	22.34	21.17	38.45	17.66	20.79	32.55	12.61	19.94

Period.	1884.			1885.		
Storage	21.42	20.20	1.22	18.58	13.63	4.95
Growing	12.14	2.79	9.35	14.82	3.20	11.62
Replenishing	8.51	2.61	5.90	11.76	5.61	6.15
Year	42.07	25.60	16.47	45.16	22.44	22.73

[a] Not included in mean. [b] Rainfall computed, approximate.

TABLE NO. 13.—*Mean or average rainfall, run-off, and evaporation for storage, growing, and replenishing periods for 12 streams of the United States.*

Period.	Muskingum River, from 1888 to 1895, eight years. Catchment area, 5,928 square miles.			Genesee River, from 1890 to 1898, nine years. Catchment area, 1,070 square miles.			Croton River, from 1877 to 1899, twenty-three years. Catchment area, 338.8 square miles.		
	Rain.	Run-off.	Evaporation.	Rain.	Run-off.	Evaporation.	Rain.	Run-off.	Evaporation.
Storage	18.8	9.6	9.2	19.4	10.5	8.9	23.7	16.8	6.9
Growing	11.6	1.7	9.9	11.5	1.7	9.8	13.6	2.6	11.0
Replenishing	9.3	1.8	7.5	9.4	2.0	7.4	12.1	3.4	8.7
Year	39.7	13.1	26.6	40.3	14.2	26.1	49.4	22.8	26.6

Period.	Lake Cochituate, from 1863 to 1900, thirty-eight years. Catchment area, 18.9 square miles.			Sudbury River, from 1875 to 1900, twenty-six years. Catchment area, 78.2 square miles.[a]			Mystic Lake, from 1878 to 1895, eighteen years. Catchment area, 26.9 square miles.		
	Rain.	Run-off.	Evaporation.	Rain.	Run-off.	Evaporation.	Rain.	Run-off.	Evaporation.
Storage	23.1	14.9	8.2	23.5	17.9	5.6	22.4	15.1	7.3
Growing	11.6	2.1	9.5	10.7	1.7	9.0	10.9	2.3	8.6
Replenishing	12.4	3.3	9.1	11.9	3.0	8.9	10.8	2.6	8.2
Year	47.1	20.3	26.8	46.1	22.6	23.5	44.1	20.0	24.1

Period.	Neshaminy Creek, from 1884 to 1899, sixteen years. Catchment area, 139.3 square miles.			Perkiomen Creek, from 1884 to 1899, sixteen years. Catchment area, 152 square miles.			Tohickon Creek, from 1884 to 1898, fifteen years. Catchment area, 102.2 square miles.		
	Rain.	Run-off.	Evaporation.	Rain.	Run-off.	Evaporation.	Rain.	Run-off.	Evaporation.
Storage	23.1	17.2	5.9	23.2	16.7	6.5	24.2	20.5	3.7
Growing	13.4	2.7	10.7	13.7	3.1	10.6	14.6	3.5	11.1
Replenishing	11.1	3.2	7.9	11.1	3.8	7.3	11.3	4.4	6.9
Year	47.6	23.1	24.5	48.0	23.6	24.4	50.1	28.4	21.7

Period.	Hudson River, from 1888 to 1901, fourteen years. Catchment area, 4,500 square miles.			Pequannock River, from 1891 to 1899, nine years. Catchment area, 63.7 square miles..			Connecticut River, from 1872 to 1895, eleven years.[b] Catchment area, 10,234 square miles.		
	Rain.	Run off.	Evaporation.	Rain.	Run-off.	Evaporation.	Rain.	Run-off.	Evaporation.
Storage	20.6	16.1	4.5	23.0	19.7	3.3	18.9	15.1	3.8
Growing	12.7	3.5	9.2	12.7	3.1	9.6	13.8	3.3	10.5
Replenishing	10.9	3.7	7.2	11.1	4.0	7.1	10.3	3.6	6.7
Year	44.2	23.3	20.9	46.8	26.8	20.0	43.0	22.0	21.0

[a] See explanatory matter.

[b] Three years omitted from mean.

TABLE No. 14.—*Low-water periods on Muskingum River.*

[Catchment area=5,828 square miles.]

First period.				Second period.				Third period.			
Months.	Gross depth, in inches.	Evaporation from water surface.	Net run-off, in inches.	Months.	Gross depth, in inches.	Evaporation from water surface.	Net run-off, in inches.	Months.	Gross depth, in inches.	Evaporation from water surface.	Net run-off, in inches.
1887.											
December	0.18	0.01	0.17								
1888.											
January	1.24	.01	1.23								
February	1.12	.01	1.11								
March	1.38	.01	1.37								
April	.80	.01	.79	1891.				1894.			
May	.45	.02	.43	May	0.45	0.02	0.43	April	0.75	0.01	0.74
June	.29	.02	.27	June	.91	.02	.89	May	.74	.02	.72
July	.81	.03	.78	July	.51	.03	.48	June	.42	.02	.40
August	.67	.03	.64	August	.35	.03	.32	July	.13	.03	.10
September	.61	.02	.59	September	.17	.03	.14	August	.11	.03	.08
October	.77	.02	.75	October	.26	.02	.24	September	.15	.03	.12
November	2.01	.01	2	November	.94	.01	.93	October	.10	.02	.08
December	.84	.01	.83	December	1.03	.01	1.02	November	.16	.01	.15
1889.				1892.				December	.36	.01	.35
January	1.89	.01	1.88	January	.74	.01	.73	1895.			
February	1.42	.01	1.41	February	2.40	.01	2.39	January	1.67	.01	1.66
March	.71	.01	.70	March	1.26	.01	1.25	February	.12	.01	.11
April	.88	.01	.87	April	1.38	.01	1.37	March	1.20	.01	1.19
May	.28	.02	.26	May	2.25	.02	2.23	April	.59	.01	.58
June	.47	.02	.45	June	2.30	.02	2.28	May	.10	.02	.08
July	.55	.03	.52	July	.75	.03	.72	June	.17	.02	.15
August	.22	.03	.19	August	.60	.03	.57	July	.21	.03	.18
								August	.11	.03	.08

September	.14	.12	.12	September	.28	.12	.20	October	.08	.12	.15							
October	.14	.02	.12	October	.20	.12	.18	November	.16	.01								
November	.68	.01	.67	November	.19	.01	.18											
				December	.24	.01	.23											
				1888.														
				January	.37	.01	.36											
24 months	18.55	.40	18.15	21 months	17.58	.38	17.20	20 months	7.46	.37	7.09							

TABLE No. 15.—*Low-water periods on Genesee River.*

[Catchment area at point of gaging = 1,070 square miles; above proposed dam = 1,000 square miles.]

First period.				Second period.			
Month.	Gross depth, in inches.	Evaporation from water surface.	Net run-off, in inches.	Month.	Gross depth, in inches.	Evaporation from water surface.	Net run-off, in inches.
1894.		*Per cent.*		1896.		*Per cent.*	
June	1.10	0.05	1.05	June	0.39	0.05	0.34
July	.14	.06	.08	July	.24	.06	.18
August	.22	.07	.15	August	.20	.05	.15
September	.98	.04	.89	September	.16	.03	.13
October	.44	.03	.41	October	1.74	.02	1.72
November	.82	.02	.80	November	.82	.02	.80
December	.61	.01	.60	December	.79	.01	.78
1895.				1897.			
January	.66	.01	.65	January	.78	.01	.77
February	.22	.01	.21	February	.79	.01	.78
March	1.94	.02	1.92	March	2.65	.02	2.63
April	2.01	.03	1.98	April	1.31	.03	1.28
May	.19	.06	.13	May	.99	.06	.93
June	.13	.06	.07	June	.44	.06	.38
July	.11	.05	.06	July	.46	.06	.40
August	.12	.04	.08	August	.44	.05	.39
September	.10	.03	.07	September	.18	.04	.14
October	.11	.02	.09	October	.18	.03	.15
November	.47	.01	.46	November	.37	.02	.35
December	1.32	.01	1.41	December	.95	.01	.94
1896.							
January	.47	.01	.46				
February	.91	.01	.90				
21 months	13.02	.65	12.37	19 months	13.88	.64	13.24

INDEX.

	Page
land, cited	11-12, 39
st. rainfall on	15
. W. S., cited	30
anger of using	28
cited	9
.. cited	11
., cited	18, 42
rea, relations of run-off to	33-35
Lake, hydrography of	57, 58, 60-61, 67, 69, 88-89, 99
E., cited	51
tables for Dickens's and s formulas, citation of	26-27
n. *See* Negative evaporation.	
River, hydrography of	57, 62, 98, 99
/., cited	27
nulas for run-off, statement	27
r, hydrography of	50, 57, 58, 59-60, 75, 81, 86-87, 99
rshed, forestation of, discus-	55-56
ormula for maximum dis- statement of	26
f streams, formula for com-	26
in-off.	
computation of, from rain-	31
ld's formula for	38
e." statistics concerning	40-43
l relations of	30-31, 39, 40
..cited	55
Desmond, cited	9, 10, 11, 38, 50, 71
formula for evaporation, ent of	38
ams, measurement of, units	20
a	20-21
ts of	19, 53-56
R., cited	60
ted	9
treams, advantages of	24-25
er, gagings of, remarks con-	37
aphy of	56, 58, 59, 64, 72, 85, 99
er Basin, geology of	47
r in	36
nd stream flow in	14-15, 21
ucture, relations of, to run-	46-52
es, and Warrington, cited	40
region, rainfall in	14
Ground water, formulas concerning	31-32
growth of streams by accession of	44
low, effect of	30
movements of	43-44, 45-46
Harrington, M. W., cited	13
Heberden, William, cited	11
Henry, A. J., cited	10, 18
Herschel, Clemens, cited	9, 20, 21
Hough, F. B., cited	53
Hudson River, gagings of, remarks concerning	37
hydrography of	57, 59, 62, 63, 64, 70, 71, 72, 77, 78, 80, 96, 99
Hudson River Basin, geology of	51-52
rainfall in	14
Johnston, T. T., cited	33
King, F. H., cited	43, 44
Lake Cochituate, hydrography of	57, 58, 60-61, 67, 69, 88-89, 99
Lakes, water storage in, influence of, on stream flow	23
Lawes, Gilbert, and Warrington, cited	40
Los Angeles River, hydrography of	44-45
Low-water periods, consideration of	35-36
Mississippi Valley, rainfall in	15
Mohawk River Basin, geology of	48
Mullins, J., cited	26
Muskingum River, hydrography of	56, 58, 59, 67, 73, 80, 85, 99, 100-101
Muskingum River Basin, evaporation in	35-36
geology of	48
low water in	35-36
rainfall and stream flow in	21
Mystic Lake, hydrography of	57, 58, 61, 92, 99
Negative evaporation, statistics concerning	40-43
Neshaminy Creek, hydrography of	57, 58, 61-62, 93, 99
New York State, rainfall in	13-15, 16
Noble, T. A., cited	13
Oswego River, run-off of	23
Oswego River Basin, geology of	47
Pacific coast region, rainfall in	15
Passaic River, hydrography of	74, 81
Pequannock River, hydrography of	52, 57, 59, 62, 97, 99
Percentages, danger of using	28-29
Perkiomen Creek, hydrography of	57, 58, 62, 94-95, 99
Rainfall, cause of	10-11
effect of forests on	53
increase of, problem concerning	13
measurement of	11-12

	Page.
Rainfall, minimum, determination of	12-13
periods of (storage, growing, and replenishing)	16
records of, length of time required for good series	17-19
relations of, to altitude	13
relations of, to evaporation	30-31
River flow, measurement of, units for	20
minimum	20-21
Rivers, classes of, as regards run-off	22
See also Streams.	
Rocky Mountain region, rainfall in	15
Run-off, annual, computation of	24
computation of, discrepancies in	24
minimum, characteristics of	21-22
conditions influencing	9
data required for computing	25
effect of forests on	53
estimation of, from rainfall diagrams	22-23
formulas for computing	25-26, 27, 33
measurement of, units for	20
minimum, amount of	20-21
relations of, to catchment area	33-35
relations of, to geologic structure	46-52
Russell, Thomas, cited	15, 33
Russell's formulas for run-off, statement of	33
Ryves's formula for maximum discharge, statement of	26
Skaneateles Lake, hydrography of	49
Slichter, C. S., cited	45
Soils, water capacity of, table showing	43
Storage of water in lakes, influence of, on stream flow	23
Stream flow, laws of	19
minimum	20-21
Stream gagings, advantages of	24-25
Streams, classification of	22, 58
Sudbury River, hydrography of	57, 58, 61, 65, 66, 67, 75, 78, 79, 81, 90-91, 99
Sweet, S. H., cited	49
Symons, G. J., cited	42
Tate, Thomas, cited	39
Thames River, England, hydrography of	42-43
Tohickon Creek, hydrography of	57, 58-59, 62, 99
Transactions American Society of Civil Engineers, citations from	9, 10
Turner, E. T., cited	13, 14
Underground flow of streams, instances of	48-49
Velschow, F. A., cited	10
Vermeule, C. C., cited	19, 21, 24, 30, 31, 32, 46, 52, 55
Vermeule's formulas for relation between evaporation and precipitation, statement of	30-31
Wallis, H. S., cited	81
Warrington, Lawes, and Gilbert, cited	40
Water flow, measurement of, units for	20
Weir measurements, variation in	57
Wind, effect of	30, 46

O

Stanford University Libraries
3 6105 007 631 174

SEP 23 2003

664285